WRDC-TR-90-2121
Volume III

2

Thermal Energy Storage and Heat Transfer Support Program

TASK-5 HEAT PIPE LIFE TEST STUDY; FACILITIES UPGRADING AND MAINTENANCE

R. Ponnappan

UES, Inc.
4401 Dayton-Xenia Road
Dayton, OH 45432-1894

1 March 1991

Final Report for Period June 1987 - September 1990

Approved for Public Release; Distribution Unlimited

Aero Propulsion and Power Laboratory
Wright Laboratory
Air Force Systems Command
Wright Patterson AFB, OH 45433-6563

NOTICE

WHEN GOVERNMENT DRAWINGS, SPECIFICATIONS, OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY GOVERNMENT-RELATED PROCUREMENT, THE UNITED STATES GOVERNMENT INCURS NO RESPONSIBILITY OR ANY OBLIGATION WHATSOEVER. THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA, IS NOT TO BE REGARDED BY IMPLICATION, OR OTHERWISE IN ANY MANNER CONSTRUED, AS LICENSING THE HOLDER, OR ANY OTHER PERSON OR CORPORATION; OR AS CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE, OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

THIS REPORT HAS BEEN REVIEWED BY THE OFFICE OF PUBLIC AFFAIRS (ASD/PA) AND IS RELEASABLE TO THE NATIONAL TECHNICAL INFORMATION SERVICE (NTIS). AT NTIS IT WILL BE AVAILABLE TO THE GENERAL PUBLIC INCLUDING FOREIGN NATIONS.

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

ANGEL S. REYES
Power Technology Branch
Aerospace Power Division
Aero Propulsion and Power Directorate

JERRY E. BEAM
Power Technology Branch
Aerospace Power Division
Aero Propulsion and Power Directorate

FOR THE COMMANDER

William U. Borger
Chief, Aerospace Power Division
Aero Propulsion and Power Directorate

IF YOUR ADDRESS HAS CHANGED, IF YOU WISH TO BE REMOVED FROM OUR MAILING LIST, OR IF THE ADDRESSEE IS NO LONGER EMPLOYED BY YOUR ORGANIZATION PLEASE NOTIFY WL/POOS-3, WRIGHT-PATTERSON AFB, OH 45433-6563 TO HELP MAINTAIN A CURRENT MAILING LIST.

COPIES OF THIS REPORT SHOULD NOT BE RETURNED UNLESS RETURN IS REQUIRED BY SECURITY CONSIDERATIONS, CONTRACTUAL OBLIGATIONS, OR NOTICE ON A SPECIFIC DOCUMENT.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b RESTRICTIVE MARKINGS: N/A

2a. SECURITY CLASSIFICATION AUTHORITY: N/A

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3 DISTRIBUTION / AVAILABILITY OF REPORT: Approval for public release; Distribution is unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S): UES-799-TR-90-005

5. MONITORING ORGANIZATION REPORT NUMBER(S): WRDC-TR-90-2121, Volume III

6a. NAME OF PERFORMING ORGANIZATION: UES, Inc.

6b OFFICE SYMBOL (If applicable): SSED

7a. NAME OF MONITORING ORGANIZATION: Aero Propulsion & Power Lab (WL/POOS) Wright Laboratory

6c. ADDRESS (City, State, and ZIP Code): 4401 Dayton-Xenia Road Dayton, OH 45432-1894

7b ADDRESS (City, State, and ZIP Code): Wright-Patterson AFB, OH 45433-6563

8a. NAME OF FUNDING / SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F33615-87-C-2738

8c. ADDRESS (City, State, and ZIP Code):

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO
62203F	3145	20	51

11 TITLE (Include Security Classification) Thermal Energy Storage and Heat Transfer Support Program Vol. III: Task - 5 Heat Pipe Life Test Study; Facilities Upgrading and Maintenance

12. PERSONAL AUTHOR(S) Rengasamy Ponnappan

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Jun 87 TO Sep 90	1 March 1991	79

16. SUPPLEMENTARY NOTATION
Apart from the contractual efforts described in this report, a substantial amount of Air Force support was furnished to the contractor.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Heat Pipe Life Test; Ammonia, Methanol, R-21, Sodium and Potassium Heat Pipes; Corrosion Compatibility; Gas Generation; Temperature Profile; Data Logging

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report describes the recommissioning, upgrading, and maintaining of thirty low and five high temperature heat pipe life test rigs. This is an ongoing research effort, originally put together by NASA LeRC, continued by the Air Force. The 92 cm long 1.27 cm dia. spacecraft-type heat pipes have completed nearly 74,000 hours of life tests. They exhibit varying ΔTs across the length and symptoms of gas accumulation. Life test status and temperature profile for each pipe are presented. The sodium and potassium pipes have undergone relatively less hours of testing (34,000 hours) only. These five pipes are exhibiting normal status. All the life tests will continue till failure and there will be updates of this report.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Angel S. Reyes	513-255-2922	WL/POOS-3

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF TABLES

FOREWORD

This final report was prepared as part of the contract deliverables under the "Thermal Energy Storage and Heat Transfer Support Program," contract F33615-87-C-2738. This contract was administered by the Aero Propulsion and Power Laboratory (APPL) of Wright Research and Development Center (WRDC) (now Wright Laboratory (WL)) and co-sponsored by the Strategic Defense Initiative Organization (SDIO). Dr. J. E. Beam, Ms. J. E. Johnson, Mr. M. Morgan, and Mr. A. S. Reyes were the Air Force Technical Monitors at various stages of this program.

The present report outlines the research effort performed under Task-5 Heat Pipe Life Test Study covering the specific work done on the refurbishment/upgrading of the as-received NASA equipment and the conduct of the functional life tests on the thirty low and five high temperature heat pipes. The other tasks of this program, namely, Task-1 Heat Transport System Study, Task-2 Thermal Energy Storage Study, Task-3 Innovative Radiator Study, and Task-4 Thermionics Study are covered under separate documents.

The entire work described here was performed on-site at the Thermal Laboratory (WL/POOS-3) by UES, Inc., Dayton, Ohio with Dr. R. Ponnappan as the Task Principal Investigator and Program Manager. J. Tennant (UES), M. D. Ryan (UES), and D. Reinmuller (WL) provided the technical support. UES Scientific and Engineering Services Division and Drafting Group provided documentation services. Mr. A. S. Reyes (WRDC) and Joella Pinckney (Selectech) helped in plotting the graphs.

NOMENCLATURE

AL	Aluminum
DYNA	Dynatherm Corporation
ET	Elapsed Time
GRUM	Grumman Corporation
HP	Hewlett-Packard
Hrs	Hours
MCDD	McDonnell-Douglas Corporation
NASA	National Aeronautics and Space Administration
R-21	Refrigerant-21 (Freon-21)
Q_{in}	Heat Input to the Evaporator
SS	Stainless Steel
T.C.	Thermocouple
TRW	TRW Corporation
WRDC	Wright Research and Development Center

SECTION I
INTRODUCTION

Between 1974 and 1981, NASA Lewis Research Center conducted a research program to assess the performance of commercially available spacecraft-quality heat pipes designed to operate in the neighborhood of 30°C. As a part of this program, NASA procured from different manufacturers 30 heat pipes made of various working fluids, envelope materials, and wick structures. The objectives of the NASA test program were to evaluate the heat transfer capability in 1-g condition and to determine the generation of noncondensible gas due to the corrosive interaction of the working fluid and wall/wick materials. Before the work in this program could be completed as scheduled, in 1981 a de-emphasis of heat pipe research occurred at NASA LeRC and the entire program was terminated. Subsequently, all the test equipment and hardware were transferred to the Air Force Aero Propulsion Laboratory of WRDC. At the time of the termination, NASA had completed cumulative life test hours of 34,000-48,800 for the 30 heat pipes as per the details of the logbook record kept for each heat pipe[1]. NASA had published their test results in a journal paper[2]. Additional detailed information and recommissioning procedures were obtained by the Air Force from private consultants who worked for NASA on this program. An Air Force Technical Report describes these[3]. The heat pipes had been in storage for nearly 5 years while awaiting for facilities at the new home. In 1986 the test stands were recommissioned in full operational mode. To date the tests are continuing and some of the pipes have reached cumulative hours of 75,000 or more as of September 1990. Section II of this report describes the work done on these 30 low temperature test stands and the present status along with some gas generation test results.

Parallel to the low temperature heat pipe test program, NASA LeRC had an elaborate high temperature sodium and lithium in superalloy heat pipes test effort also. This program was to study the materials compatibility of several liquid metals (Li, Na, K, Cs and Hg) in tantalum alloy pipes. Two sets of test stands were used. One set of six stands with short vacuum chambers (18 inches long and 6 inches diameter) and another set of 12 long chambers (each 48 inches long and 8 inches diameter) were transferred from NASA to the Air Force. Only five out of the six short-chamber stands, now called 'high temperature vertical stands' were

recommissioned with life tests. Six out of the twelve long chambers (called 'multistands') were installed, but no heat pipes were put on test as all the 4-ft.-long superalloy heat pipes failed prior to their transfer from NASA. The post-test cut-away analysis and results of the superalloy heat pipes are reported in an Air Force final report[4]. Earlier to this, NASA had published some of their partial and inconclusive report in a heat pipe conference[5]. Along with the low temperature heat pipes, in 1986, five high temperature heat pipes (three sodium and two potassium) had been recommissioned at the WRDC facilities, and as of September 1990, they had accumulated 24,000-37,000 hours of life testing. Section III of this report describes the upgrading and functioning of the five vertical stands.

SECTION II

LOW TEMPERATURE HEAT PIPE TEST STATIONS

2.1 OBJECTIVES AND SCOPE OF THE LIFE TEST

The objectives and scope of this effort are as follows:

1) Recommission all the 30 low temperature heat pipe test stands at the extended Thermal Laboratory equipped with the centralized vacuum and cooling water circulation facility.

2) Upgrade the test stands and data acquisition system as needed and maintain them in working condition.

3) Start and run the life test on all the heat pipes at around 60°C operating temperature at all times.

4) Conduct periodical health check by monitoring the temperature profiles and report status; provide suitable corrective measures in case any problem develops.

5) Log pertinent test data monthly. The data should include temperature profile, power input and temperature drop for all the test stands.

6) Conduct gas accumulation tests by measuring the temperature profiles when the condensers are cooled to very low temperatures. These tests may be conducted at least once a year. Compute the noncondensible gas accumulation as a function of time (test hours) and record the data.

The scope of the life tests are basically the same as that NASA had spelled out(2). The heat pipes are tested under vacuum conditions and at level positions. Only external wall temperatures are monitored, and no intrusive measurement is possible with the existing setup. The pipes can be tilted adversely or favorably if needed. The internal conditions of the heat pipes cannot be altered (intentionally for studying variations) throughout the span of the life tests due to the sealed or pinched-off fill tubes configuration as opposed to valved-off fill tubes configuration.

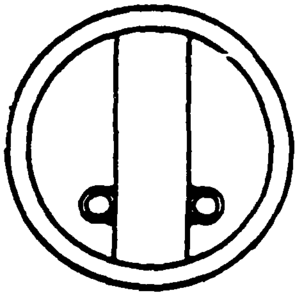
Even though no data on the design life of these heat pipes are available, it can be assumed from the industry practice that spacecraft-type heat pipes are expected to have functional life of 10 to 15 years. Hence, the life tests may be continued until the test log accumulates 131,400 hours (15 years) or until failure occurs to the heat pipes. As the failure of the pipes is gradual, degradation of performance must be carefully noticed during the periodical performance/gas generation evaluation.

2.2 DESCRIPTION OF THE TEST SETUP

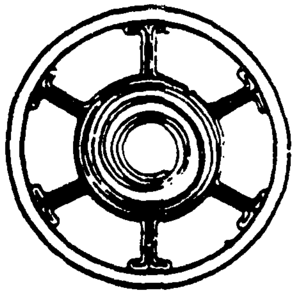
Heat pipes: The heat pipes being tested in this project are of ten different types and were purchased from four manufacturers. The fabrication and manufacturing process of these pipes are available elsewhere[2,3]. Three pipes of each type are being evaluated to give a more representative sampling of performance. All of the pipes are approximately 92 cm in length and 1.27 cm in diameter.

Figure 1 shows four different configurations of the capillary structure. All of the heat pipe containers are internally threaded over the entire length with grooves except configuration IV. Configuration I consists of a metal fiber slab wick and two screen arteries. A cap of thin foil at the evaporator end of the arteries is perforated with tiny holes to vent any gas that may be trapped in the arteries. Configuration II consists of multiple screen arteries centered by a screen support. Configuration III has an artery of spiraled screen contained in a screen tube supported by six screen pedestals. Configuration IV is an extruded axial groove structure. The material of the capillary structure for configurations I, III, and IV is type 304 stainless steel and that of configuration II is type 316 stainless steel. All envelopes are made of either 6061-T6 aluminum or of type 304 stainless steel as shown in Table 1 which provides an index of the heat pipe groups with the internal configuration, working fluid and envelope material.

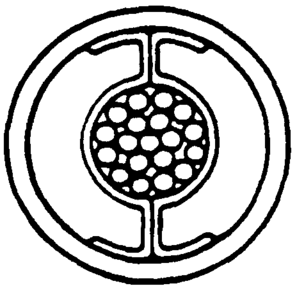
Experimental Setup and Instrumentation: Each pipe being evaluated is equipped with an electric resistance heater on the evaporator and a heat extractor on the condenser end. An annular aluminum sleeve is inserted between the heater tube and the heat pipe. Thermal grease is applied between the sleeve and the device to reduce thermal resistance. Radiation losses have been reduced by applying several wraps of aluminum foil over the heater. The electric heater



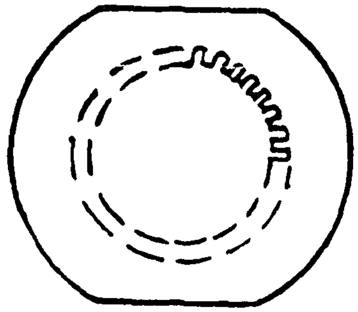
Configuration I
Slab Artery
TRW



Configuration III
Spiral Artery
Grumman



Configuration II
Tunnel Artery
McDonnell-Douglas



Configuration IV
Axial Grooves
Dynatherm

Figure 1 Capillary Structures of the Low Temperature Heat Pipes

TABLE 1. *Index of Low Temperature Heat Pipes**

HEAT PIPE GROUP	HEAT PIPE NUMBERS	CAPILLARY STRUCTURE	WORKING FLUID	ENVELOPE MATERIAL
A	1, 2, 3	I	methanol	stainless steel
B	4, 5, 6	II	methanol	stainless steel
C	7, 8, 9	III	methanol	stainless steel
D	10, 11, 12	I	ammonia	aluminum
E	13, 14, 15	II	ammonia	aluminum
F	16, 17, 18	III	ammonia	aluminum
G	19, 20, 21	II	ammonia	stainless steel
H	22, 23, 24	I	ammonia	aluminum
I	25, 26, 27	IV	ammonia	aluminum
J	28, 29, 30	I	R-21	aluminum

* All wick and artery structures were stainless steel.

is energized from an ac/dc power converter circuit built within the test stand. The 30.5-cm heat extractor consists of a series of split brass blocks of about 2.5 cm length spaced slightly apart. The block halves are penetrated by two stainless steel tubes brazed to form half a heat extractor. The two halves are clamped on the pipe by two bolts on each block. The blocks are spaced off of the condenser by shrink tubing of 0.03 cm thickness. Coolant circulates through the stainless tubes in such a manner that the average sink temperature is uniform along the condenser. Temperatures are measured by 19 iron-constantan thermocouples. Figure 2 shows the locations of the thermocouples on the pipes. There are three thermocouples on the evaporator, five on the condenser, and one each at the midpoint on the cooling blocks. For the stainless steel pipes, the thermocouples in the condenser and adiabatic sections are spot-welded, and for the aluminum

pipes, they are glued down using thermal epoxy cement. The thermocouple installation on the evaporator is described elsewhere[3]. An additional thermocouple in the evaporator is connected to a temperature controller which is set to shut the heater off when a temperature above a pre-set limit is indicated. Figure 3 shows a view of the low temperature test stands as installed in the Thermal Laboratory (WRDC).

Modifications/upgrading: The following are the changes done to the test stands in order to improve upon the performance and capabilities.

1. Digital Thermal cutout: The aging and troublesome analog type high and low temperature thermal cutouts were removed and retrofitted with 30 new digital type display and high and low temperature cutout units. This change incidentally cured the problem of interference and accidental tripping caused by the walkie-talkie communication devices on the old analog units.

2. Integrated data acquisition: An elaborate wiring of the twenty thermocouples from each heat pipe to the data collection extender units (Model Hewlett-Packard 3853A) was incorporated.

3. Thermocouple signal noise reduction: A ground loop problem was cured in the heater power circuit by removing an unwanted jumper connection. This reduced the error in temperature measurement. Figure 4 shows this modification.

4. Cooling water: A centralized demineralized water circulation to the stands was provided instead of a constant temperature cool bath NASA used. The present system has a disadvantage of overheating of the coolant inlet temperature due to the water chiller plant problems.

5. Transformer: One of the main supply transformers was too noisy. This has been removed and parallel connections were made to these stands from a similar unit in the adjoining stand.

2.3 DATA ACQUISITION

The data acquisition system involved the measurement and storage of temperature and power input data to each heat pipe. Originally, a Fluke 2280 type data logger was connected to each of the test stand and the data were read. This step was repeated for every stand once a

month and the data were stored in magnetic cartridges. As it was becoming tedious and the connectors were wearing out, this method was discontinued. In the new system, all the thermocouples from the stands are connected to extender boxes of a Hewlett-Packard data logger (Model Hewlett-Packard 3852A Data Acquisition/Control Unit) which, in turn, is connected to a personal computer. Now, all the data are directly read and stored in the computer.

The 19 iron-constantan (Type J) thermocouples provide the temperature profile along the length of the heat pipe. The power input is obtained by measuring the voltage in the heater circuit and dividing its square with the heater resistance. The heater resistances for all the stands are assumed as 30 ohms. This average value is found to be adequate for obtaining the rough value of the input power. Actually the measured resistance varied from 27.19 to 32.6 ohms when measured at the operating temperature of the heat pipes (50-70°C) except two stands as seen in Table 2. Hence, the power computed in the computer has to be multiplied by a factor of two for stations 4 and 22.

2.4 LIFE TEST DATA

The life test data gathered and stored for analysis and record are (1) power input to heater, (2) temperature profile and (3) elapsed time. These data are stored in magnetic floppy discs (5-1/4 in) on a monthly basis starting from the date of recommissioning of the stands at WRDC. A hard copy summary of this information giving the average operating temperature, maximum ΔT (end-to-end), and the elapsed time is tabulated every month. The latest summary of such information is given in Table 3.

Evaluation Criteria: The status or condition of a heat pipe can be determined by its temperature profile and the power transport capacity. If the temperature difference between the evaporator and the condenser end (ΔT) remains within 10°C, the pipe is considered to be in good condition; 10-30°C is failing, and >30°C is failed. Also, for the same operating temperature

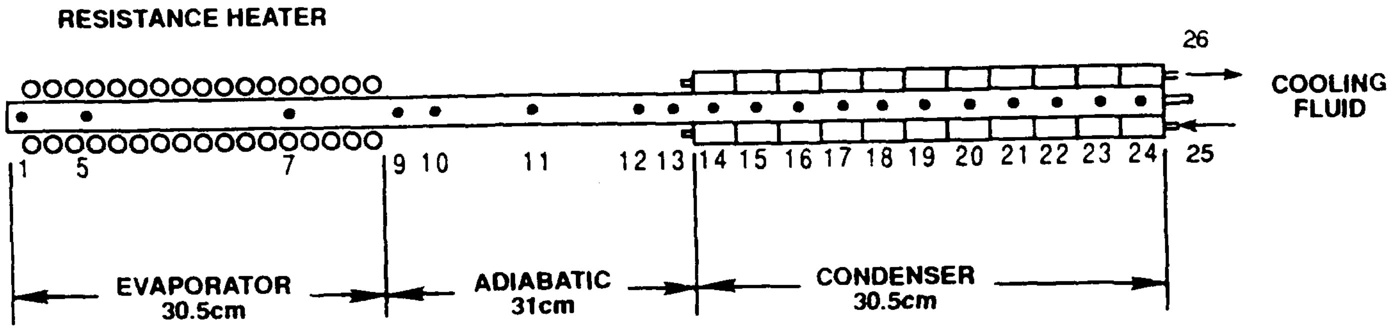


Figure 2. Location of Thermocouples.

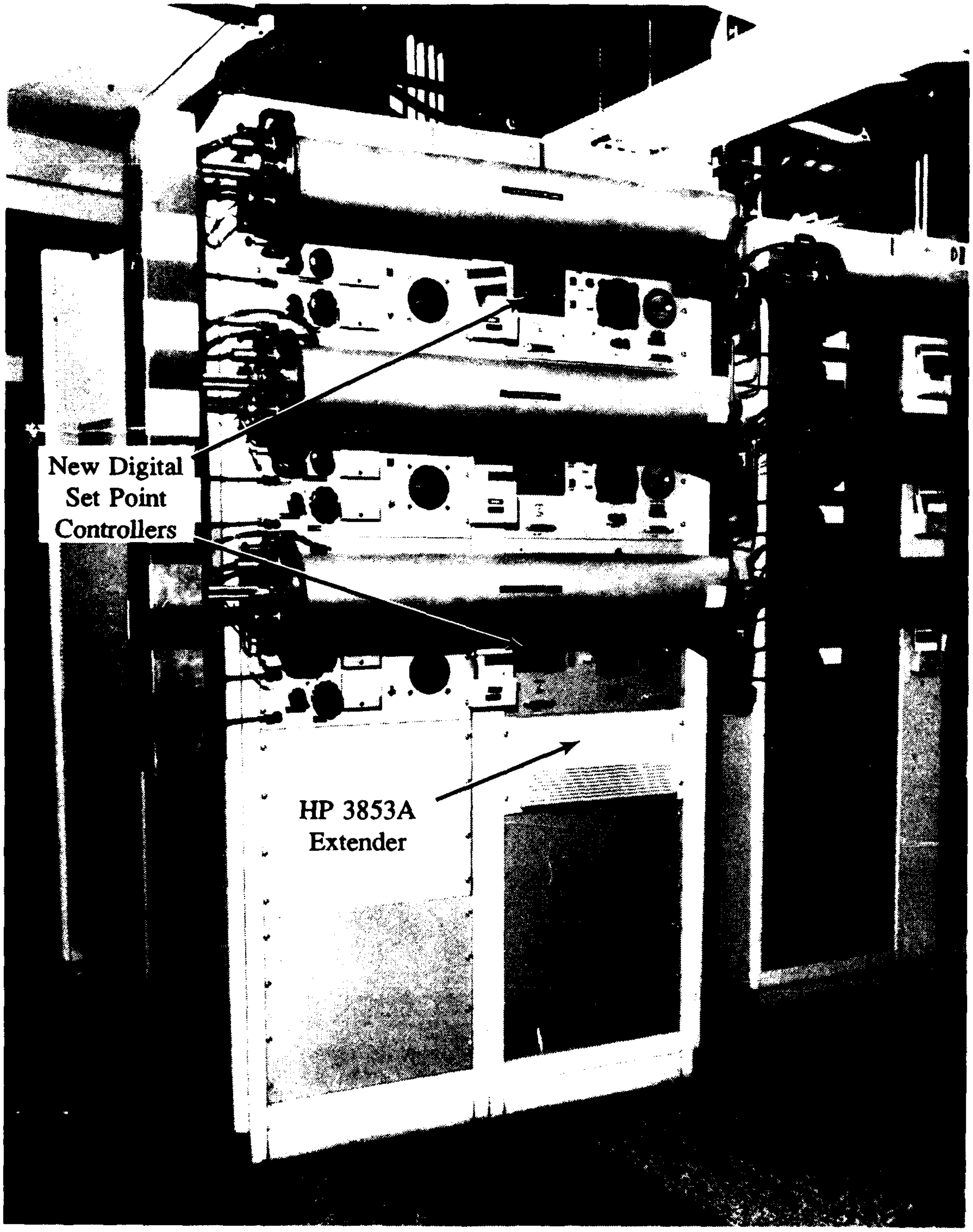


Figure 3(a). A Photographic View of the Low Temperature Heat Pipe Test Stands.

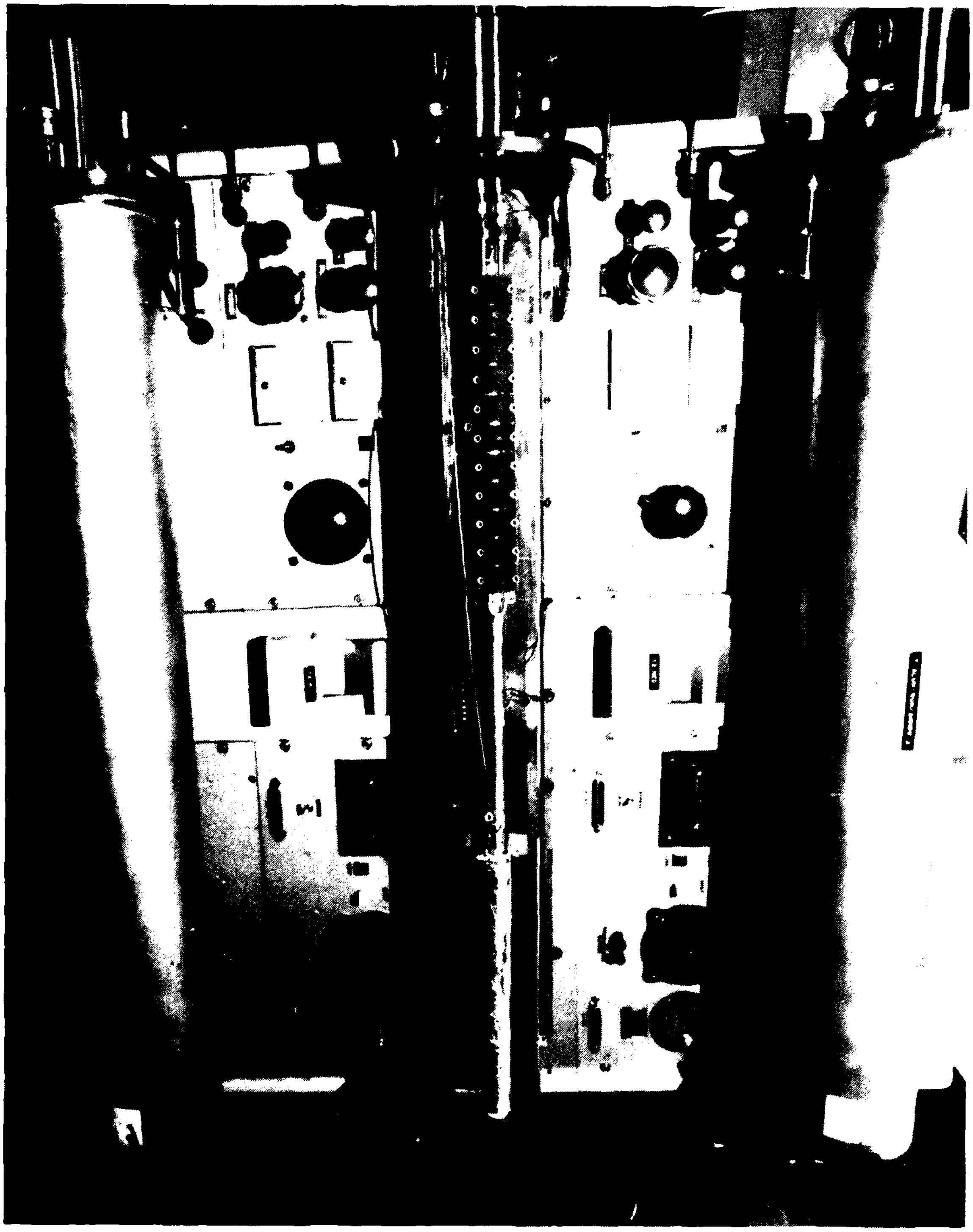


Figure 3(b). A Closeup View of a Low Temperature Test Stand With One Chamber Removed.

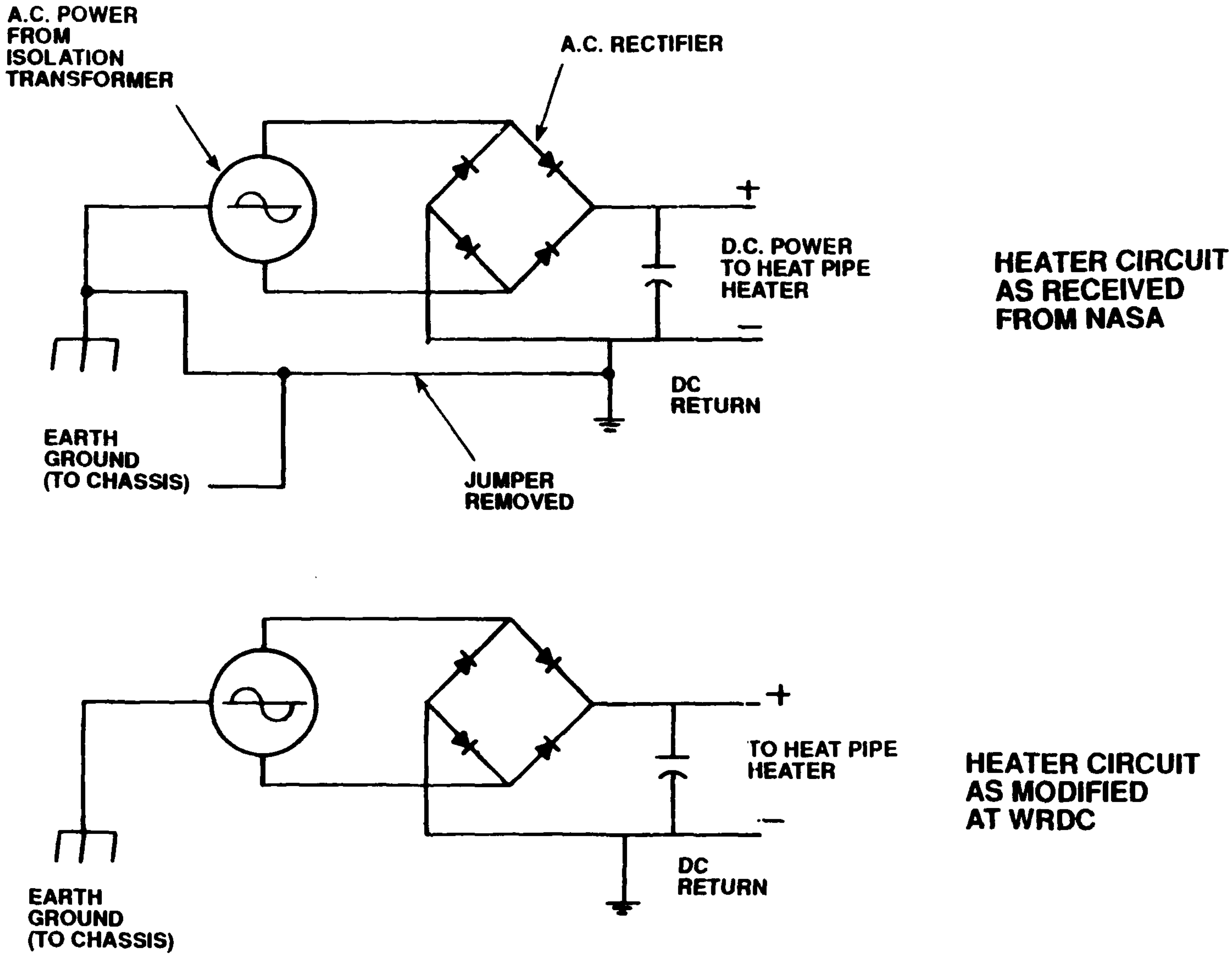


Figure 4. Evaporator Heater Circuit Modification.

TABLE 2. Resistances of the Evaporator Heaters

Stand No.	Heat Pipe Station No.	Ohmic Resistance (Ohm)
A	1	29.44
	2	29.71
	3	29.55
B	4	15.48
	5	30.0
	6	31.54
C	7	30.0
	8	27.19
	9	31.72
D	10	30.56
	11	32.37
	12	29.71
E	13	32.05
	14	30.0
	15	30.3
F	16	31.39
	17	28.18
	18	31.69
G	19	30.9
	20	30.48
	21	31.0
H	22	15.6
	23	31.85
	24	29.0
I	25	31.67
	26	31.9
	27	30.32
J	28	32.60
	29	30.88
	30	31.82

TABLE 3. Low Temperature Heat Pipe Life Test Data - Monthly Summary

DATA DATE: 9/20/90

STATION NUMBER	MANUFACTURER AND SERIAL NUMBER	ENVELOPE	FLUID	WICK	TEST START DATE AT	E.T. AT WPAFB	E.T. AT NASA	TOTAL TEST ET	AVG POWER INPUT WATTS	AVG PIPE TEMP °C	ΔT °C	SEE REMARKS
1	TRW S/N SK73101-1	S.S.	METHANOL	S.S.	12-12-86	29586	43811	73397	85	59	13.5	
2	TRW S/N SK73101-2	S.S.	METHANOL	S.S.	12-15-86	31340	43413	74753	99	58.3	26.9	
3	TRW S/N SK73101-3	S.S.	METHANOL	S.S.	12-15-86	31231	44188	75419	71.3	57.7	25.7	
4	McDONALD S/N 13	S.S.	METHANOL	S.S.	11-21-86	19899	39352	59251	30.8	58.8	26	
5	McDONALD S/N 14	S.S.	METHANOL	S.S.	12-16-86	31237	44216	75453	30	55.9	22.2	
6	McDONALD S/N 15	S.S.	METHANOL	S.S.	11-20-86	32218	43937	76155	26.1	59	25	
7	GRUMMAN S/N 7	S.S.	METHANOL	S.S.	12-24-86	29711	34008	63719	14.7	58.1	23.5	
8	GRUMMAN S/N 9	S.S.	METHANOL	S.S.	12-24-86	31278	35251	66529	35.7	56.7	23.9	
9	GRUMMAN S/N 12	S.S.	METHANOL	S.S.	12-24-86	31341	44940	76281	53.8	58	21.7	
10	TRW S/N SK74101-1	ALUMINUM	AMMONIA	S.S.	01-07-87	30695	47343	78038	70.4	58.1	24.7	
11	TRW S/N SK74101-2	ALUMINUM	AMMONIA	S.S.	01-08-87	30746	48844	79590	91.8	55.8	22	
12	TRW S/N SK73101-4	ALUMINUM	AMMONIA	S.S.	01-08-87	29581	45350	74931	1[illegible].4	52.2	19.9	
13	McDONALD S/N 7	ALUMINUM	AMMONIA	S.S.	02-12-87	23054	45908	68962	-	-	-	#1
14	McDONALD S/N 8	ALUMINUM	AMMONIA	S.S.	02-12-87	11425	46266	57691	-	-	-	#1
15	McDONALD S/N 9	ALUMINUM	AMMONIA	S.S.	02-12-87	29703	46610	76313	37.4	54.6	11.4	
16	GRUMMAN S/N 5	ALUMINUM	AMMONIA	S.S.	08-01-89	9300	46569	55869	72	58.4	14.6	
17	GRUMMAN S/N 6	ALUMINUM	AMMONIA	S.S.	02-23-87	29874	46666	76540	111.1	56.1	19.2	
18	GRUMMAN S/N 8	ALUMINUM	AMMONIA	S.S.	08-01-89	9490	46765	56255	88.4	56.5	19.2	

TABLE 3. Low Temperature Heat Pipe Life Test Data - Monthly Summary (Cont'd) DATA DATE: 9/20/90

STATION NUMBER	MANUFACTURER AND SERIAL NUMBER	ENVELOPE	FLUID	WICK	TEST START DATE AT	E.T. AT WPAFB	E.T. AT NASA	TOTAL TEST ET	AVG POWER INPUT WATTS	AVG PIPE TEMP °C	ΔT °C	SEE REMARKS
19	McDONALD S/N 11	S.S.	AMMONIA	S.S.	02-20-87	29466	44466	73932	58.8	52.5	6.1	
20	McDONALD S/N 12	S.S.	AMMONIA	S.S.	02-23-87	29115	44918	74033	69	54.4	24.1	
21	McDONALD S/N 10	S.S.	AMMONIA	S.S.	02-23-87	29430	46212	75624	102.6	56.6	9.9	
22	TRW S/N SK74100-1	ALUMINUM	AMMONIA	S.S.	12-31-86	30253	39562	69815	62	59.9	22.9	
23	TRW S/N SK74100-2	ALUMINUM	AMMONIA	S.S.	12-31-86	30790	39564	70354	52	57.8	21	
24	TRW S/N SK74100-3	ALUMINUM	AMMONIA	S.S.	12-31-86	30869	38623	69492	93.7	54.6	21.4	
25	DYNATHERM S/N 102-1	ALUMINUM	AMMONIA	NONE	11-26-86	29735	39500	69235	118.9	55.9	11.1	
26	DYNATHERM S/N 102-2	ALUMINUM	AMMONIA	NONE	11-25-86	19397	35896	55293	96.25	49.2	11.1	
27	DYNATHERM S/N 102-4	ALUMINUM	AMMONIA	NONE	11-24-86	30481	38785	69266	120	55.3	18.5	
28	TRW S/N SK74100-4	ALUMINUM	FREON 21	S.S.	12-16-86	23389	38161	61550	-	-	-	#1
29	TRW S/N SK74100-5	ALUMINUM	FREON 21	S.S.	12-16-86	30177	37612	67789	91.8	48.8	19.4	
30	TRW S/N SK74100-7	ALUMINUM	FREON 21	S.S.	12-17-86	30850	38152	69002	95.2	51.4	9.9	

E.T. - ELASPED TIME DATA (IN HOURS) REMARKS: #1 SYSTEMS DOWN DUE TO HIGH TEMPERATURE FAILURE ΔT>30°C
S.S. - STAINLESS STEEL

DESIGN DETAILS FOR ALL LOW TEMPERATURE HEAT PIPES				
OVERALL LENGTH	O.D.	EVAP. LENGTH	ADIABATIC LENGTH	CONDENSER LENGTH
36.0 INCHES	0.5 INCHES	12.0 INCHES	11.0 INCHES	12.0 INCHES

(60°C) and the condenser coolant temperature, if the transport capacity dropped over a period of time, then the pipe is supposed to be deteriorating. The gas slugged condenser end will be evident from the sudden drop in condenser temperature profile. If there is sharp rise in evaporator temperature compared to the adiabatic temperature, then it is evident that the evaporator has developed hot spots or wick damage.

Gas Generation Data: Also, the intent of this life test is to keep track of the noncondensible gases in the heat pipes. At least once a year, the pipes are run at low temperatures in order to calculate the gas from the temperature profile. The results of such study has been generated and reported[6].

2.5 RESULTS AND DISCUSSIONS

Nearly 4 years of life tests have been added to these heat pipes at the WRDC facilities. In order to assess the deterioration of their performance, the ΔT, average temperature and power input data have been compared for the 4 years. Tables 4 and 5 contain these data for stainless steel and aluminum heat pipes respectively. The power input has been reduced over the years to keep the operating temperature near 60°C which means that the pipes may be loosing their transport abilities. This effect is clouded by the fact that the coolant temperature has risen nearly 10°C over these years. The ΔT data are also somewhat irregular. No uniform increasing or decreasing trend is observed. With the mixed results, given the weightage to the experimental errors, we can conclude that there are no serious changes in the pipes in the past 4 years. However, two ammonia (#13, 14) and one R-21 (#28) pipes have gradually failed. The shutdown power was nearly 50% of the initial power in these failed pipes.

A closer inspection of the pipes' status was done by comparing the axial temperature profiles of the beginning day and the most recent day data. Figures 5-34 show the profiles of the pipes 1 through 30. In some pipes, for example H.P.# 7, 8 and 16 the gas blocked condenser lengths have significantly increased. These profiles have to be compared with those that will be obtained in the future.

From the ΔT data given in Tables 4 and 5, it can be seen that only 4 heat pipes have $\Delta T < 10°C$, 7 have ΔT ranging from 10 to 20°C and 16 have ΔT ranging from 21 to 30°C. According to our evaluation criteria established earlier, most of these pipes are in the failing region of their functional life. Sooner or later they all will develop very high ΔT's and fail.

2.6 RECOMMENDATIONS

1) The life tests on the 27 functional low temperature heat pipes must be continued as planned until failure. Besides the maximum useful lifetime data, gas accumulation and failure data would be of greater value to the industry.
2) The monthly data logging must be continued. The data may be organized in both magnetic discs and hard copy versions for future reference.
3) Annual gas accumulation tests by circulating LN_2/GN_2 (-40°C) over the ammonia and R-21 heat pipe condenser and chilled water (2°C) for the methanol heat pipe condensers should be carried out for proper estimation and record-keeping of the gas data.
4) The circulating demineralized water inlet temperature must be maintained low enough (~20°C) in order to run the pipes with maximum power input for operating them at 60°C.
5) The three failed pipes (#13, 14 and 28) must be examined closely for any test related errors before dismantling them for cut-away examination. If necessary, performance tests at lower power inputs must be conducted with positive and negative tilts. Also, any thermocouple problem should be ruled out before the pipes are dismantled.

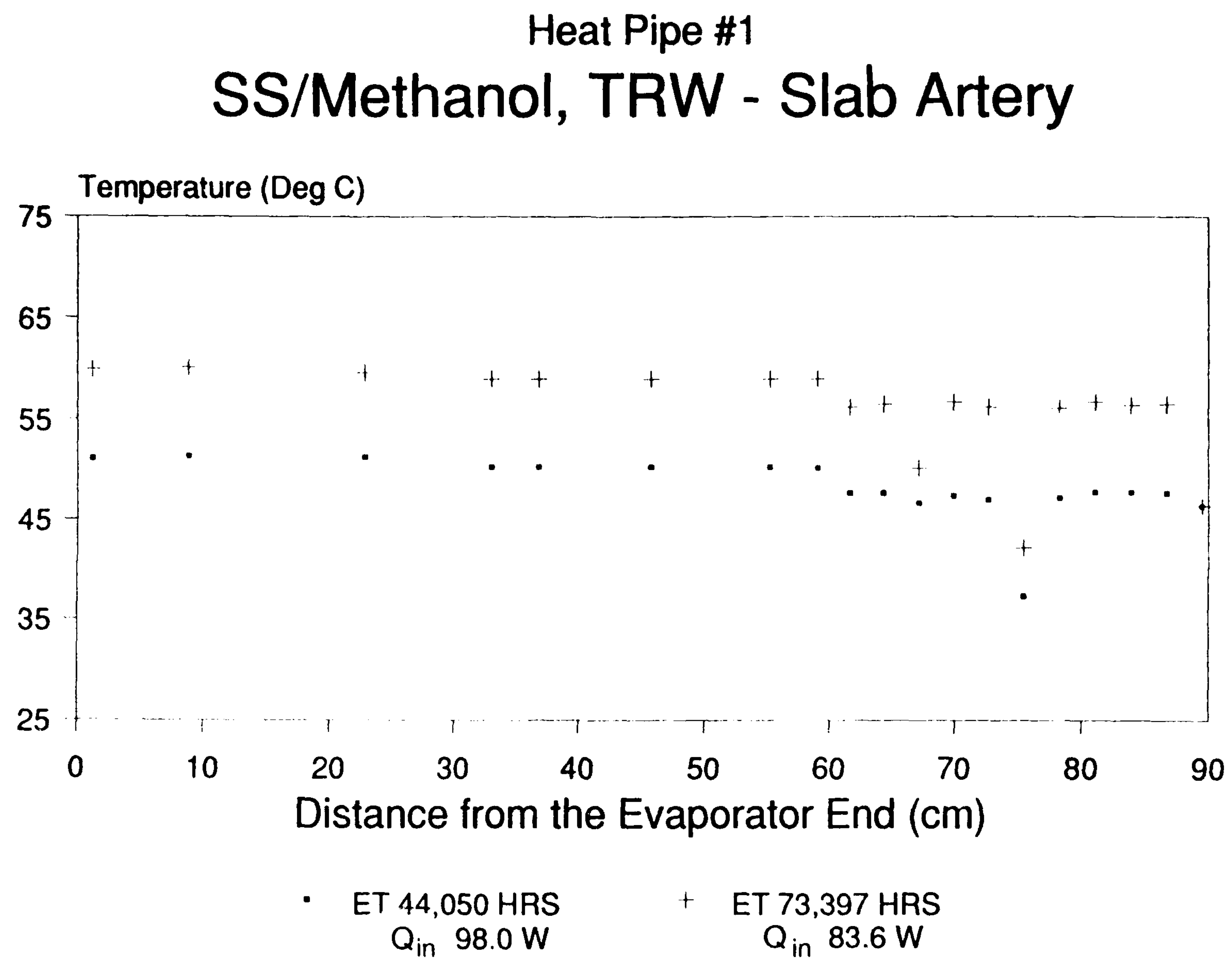


Figure 5. Axial Temperature Profiles of the Low Temperature Heat Pipe #1.

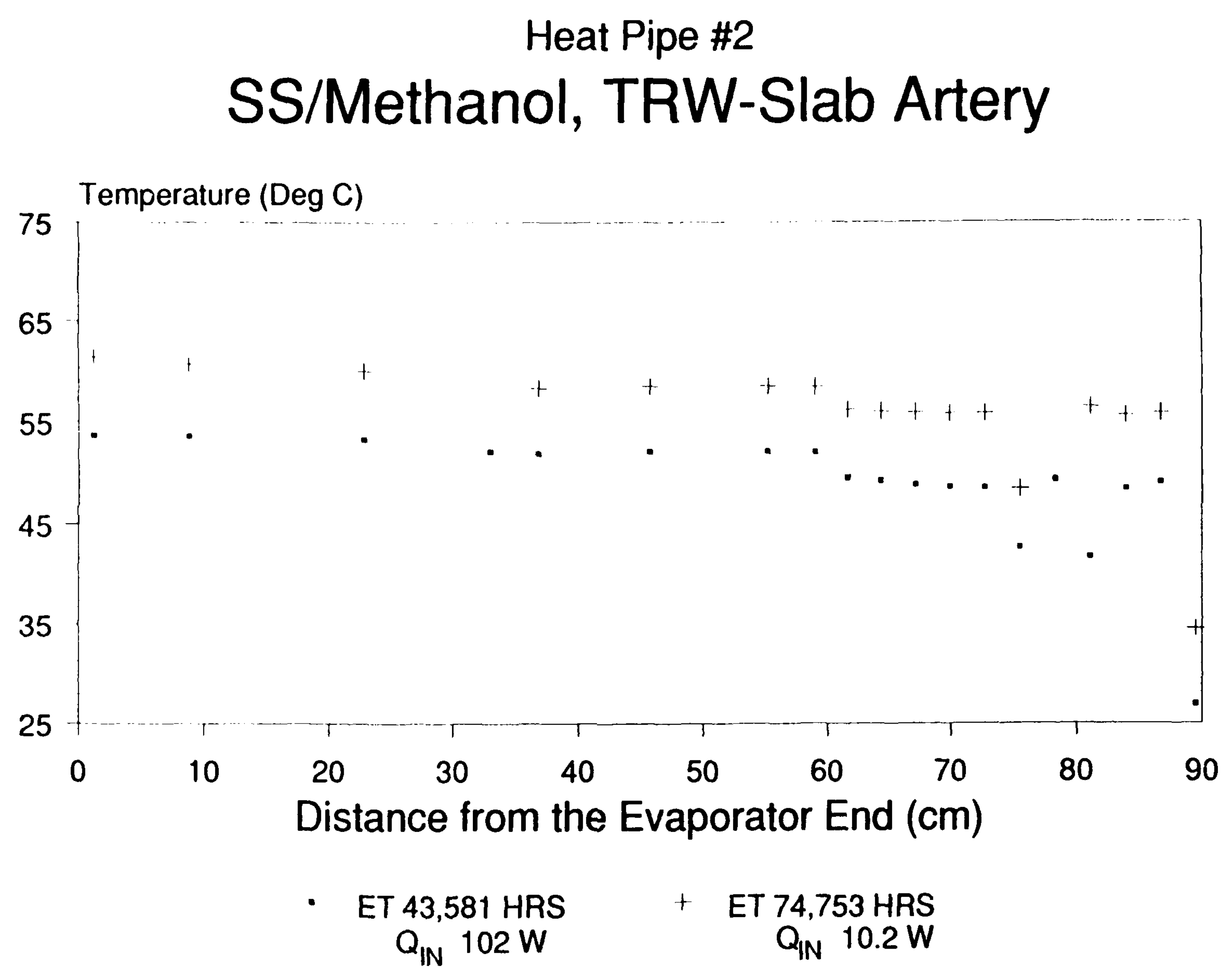


Figure 6. Axial Temperature Profiles of the Low Temperature Heat Pipe #2.

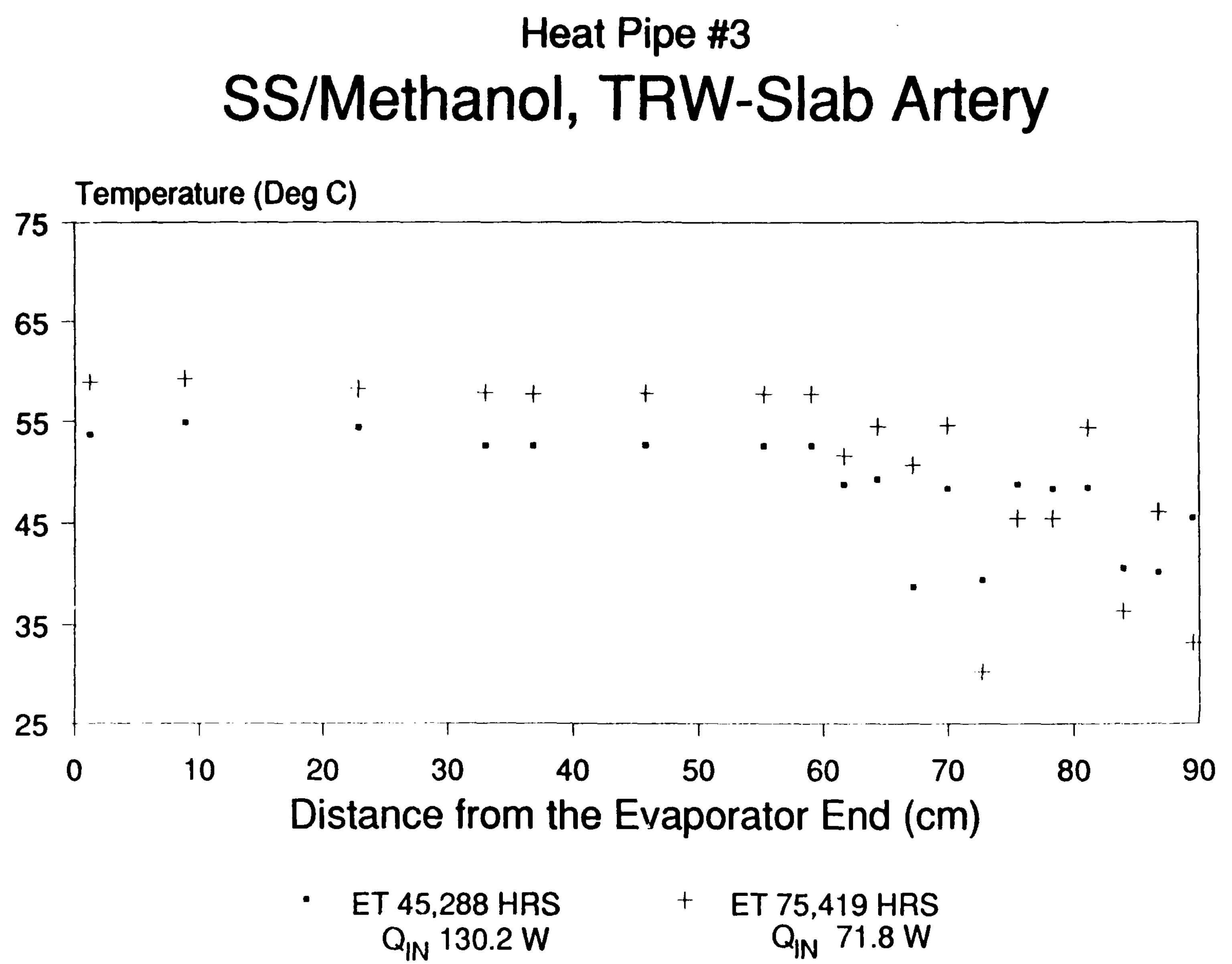


Figure 7. Axial Temperature Profiles of the Low Temperature Heat Pipe #3.

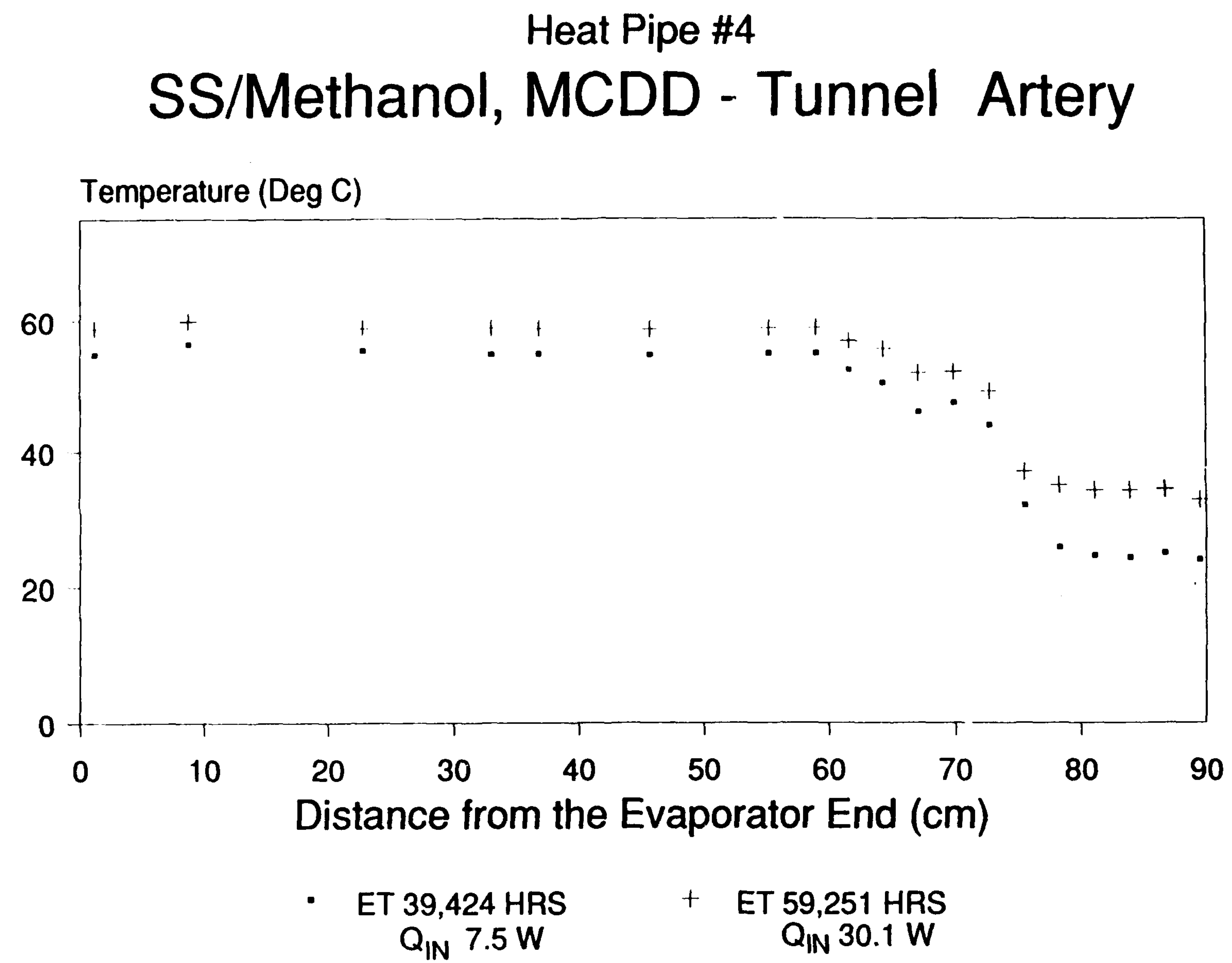


Figure 8. Axial Temperature Profiles of the Low Temperature Heat Pipe #4.

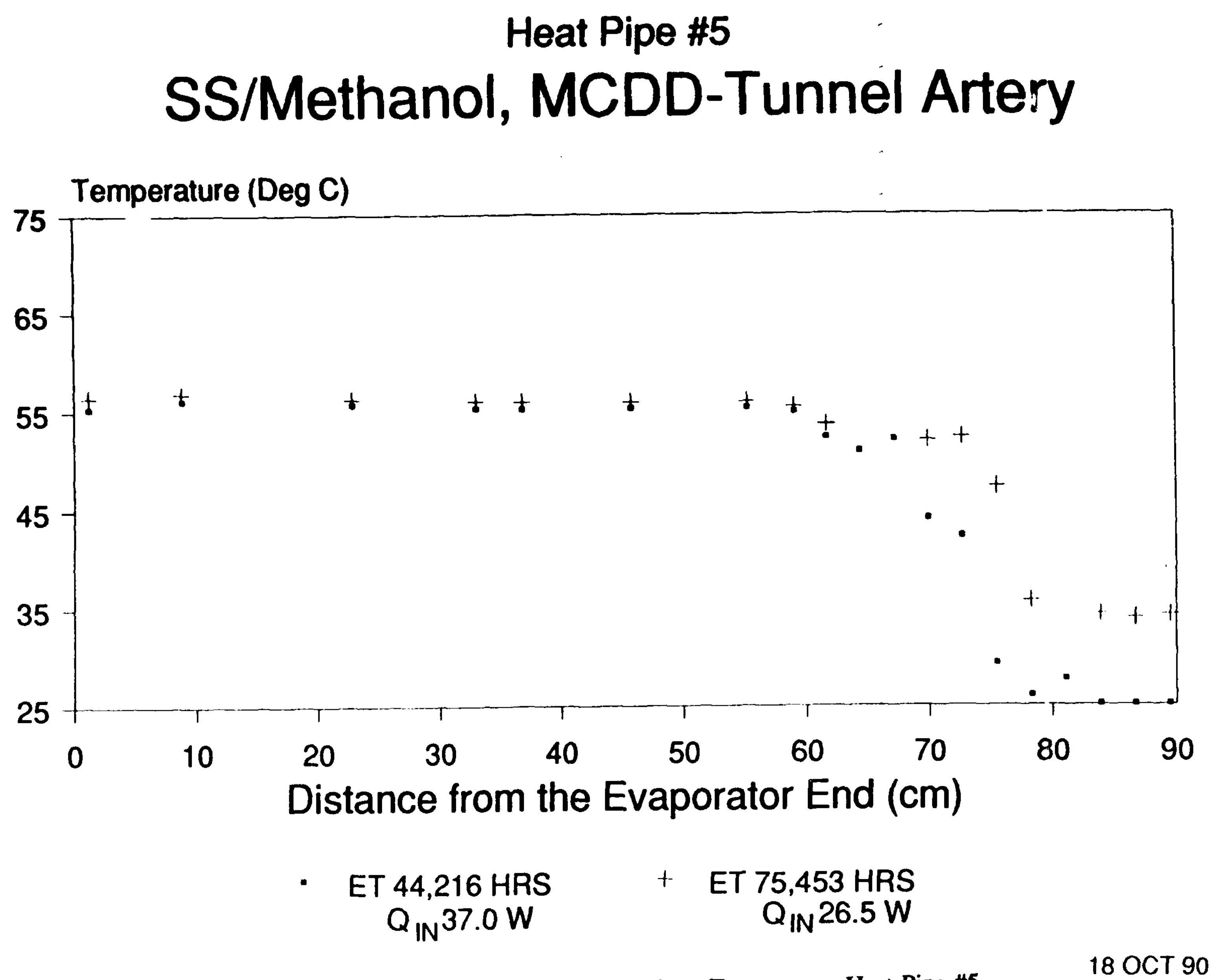


Figure 9. Axial Temperature Profiles of the Low Temperature Heat Pipe #5.

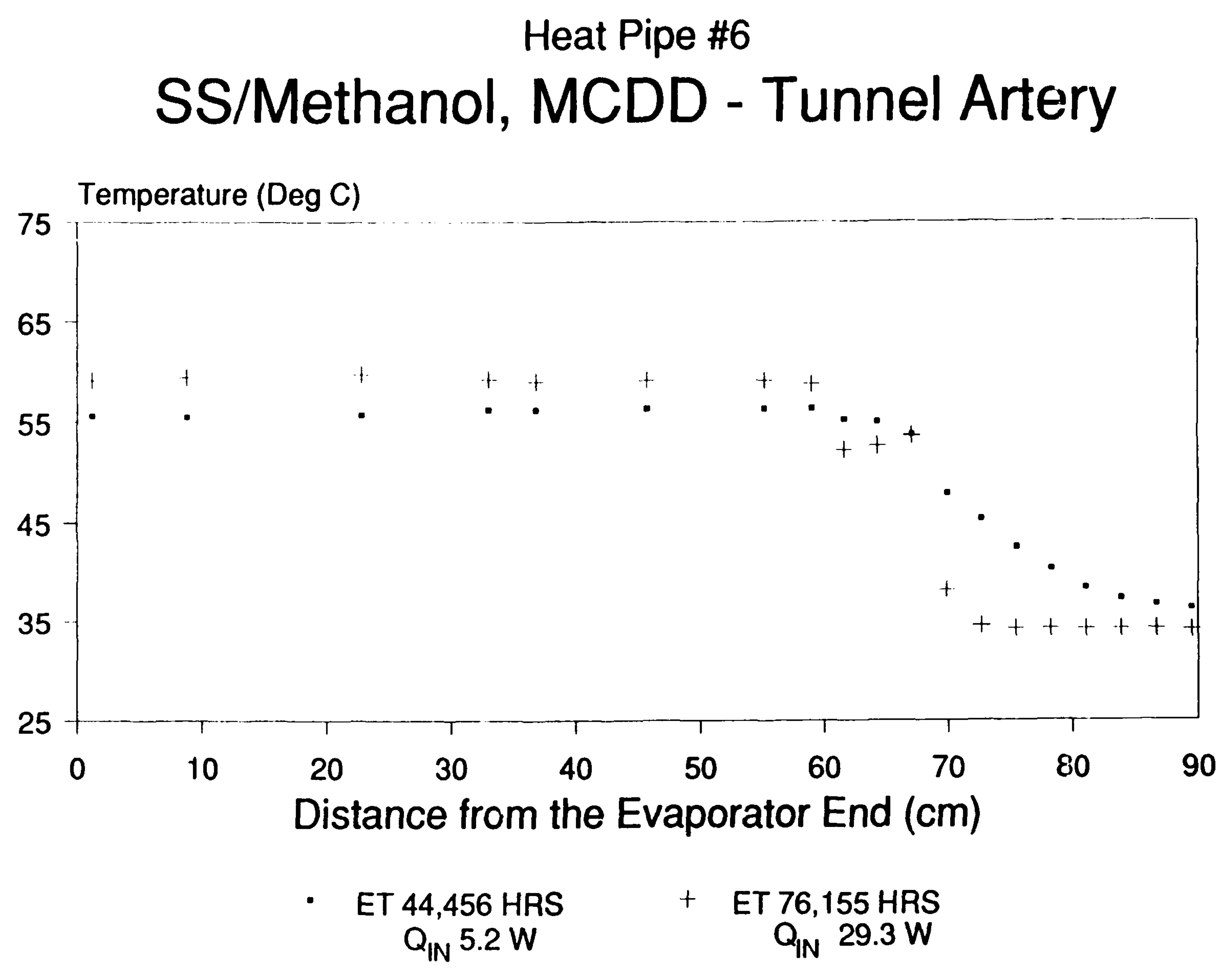


Figure 10. Axial Temperature Profiles of the Low Temperature Heat Pipes #6.

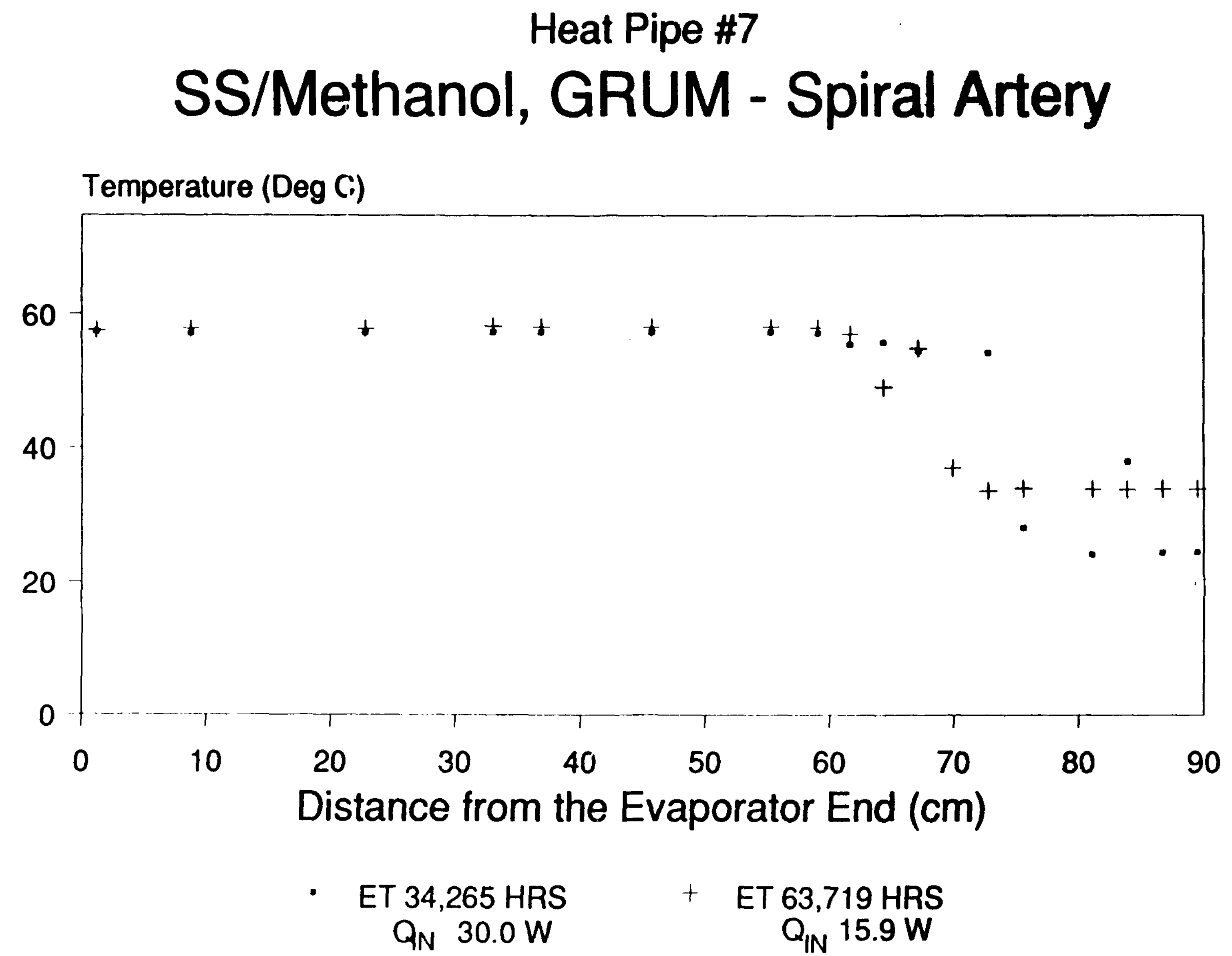


Figure 11. Axial Temperature Profiles of the Low Temperature Heat Pipes #7.

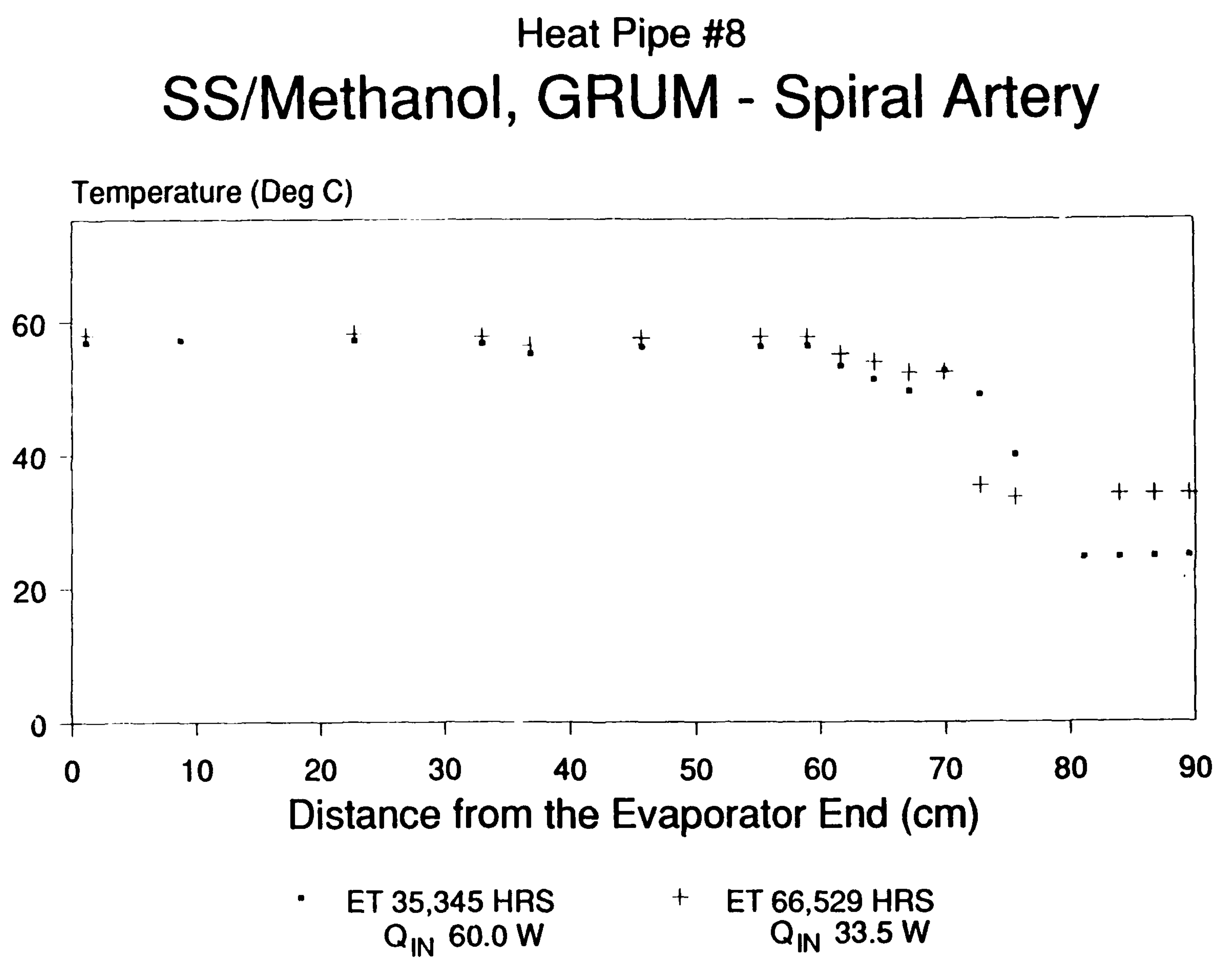


Figure 12. Axial Temperature Profiles of the Low Temperature Heat Pipes #8.

Heat Pipe #9

SS/Methanol, GRUM - Spiral Artery

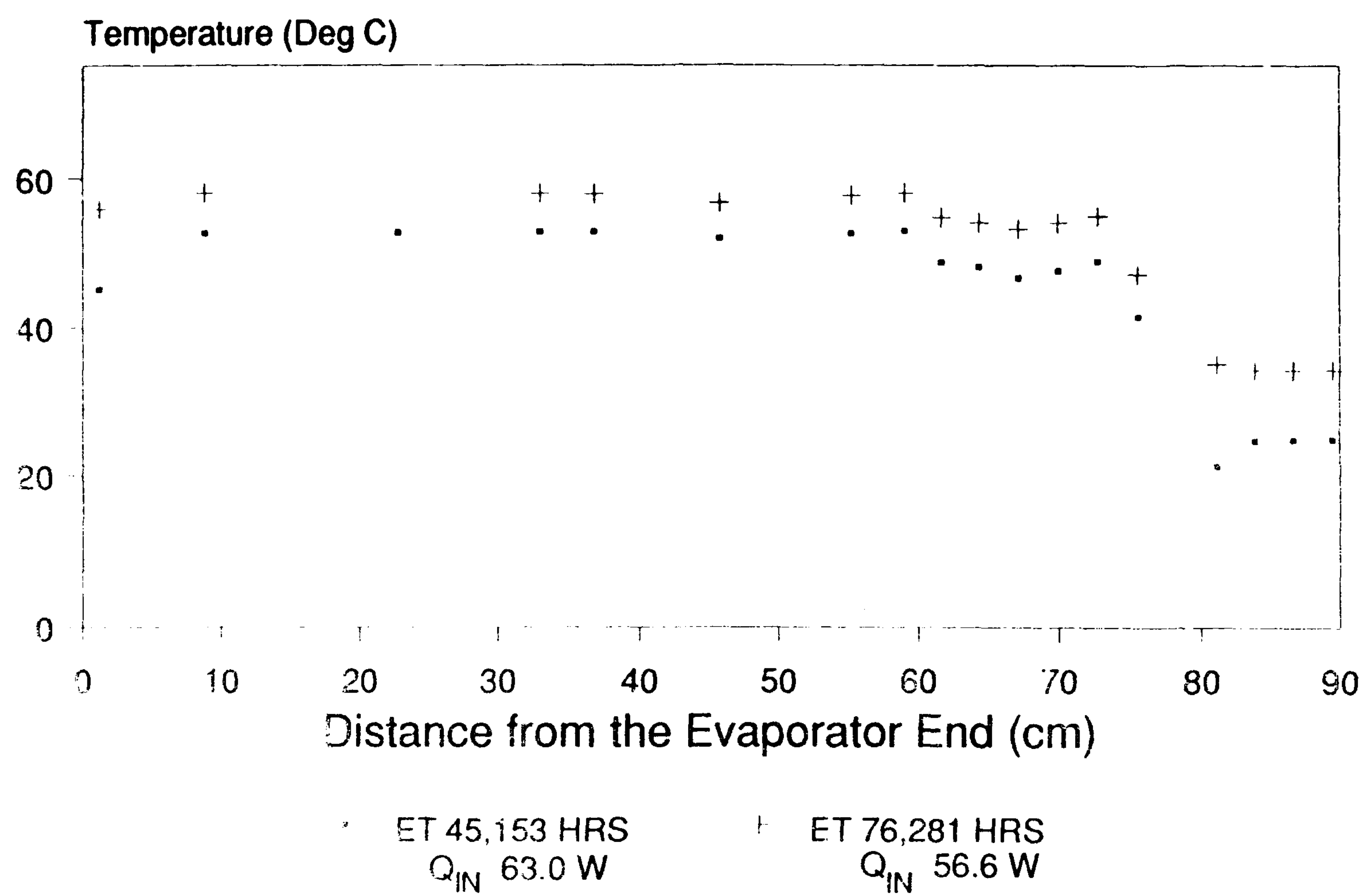


Figure 13. Axial Temperature Profiles of the Low Temperature Heat Pipes #9.

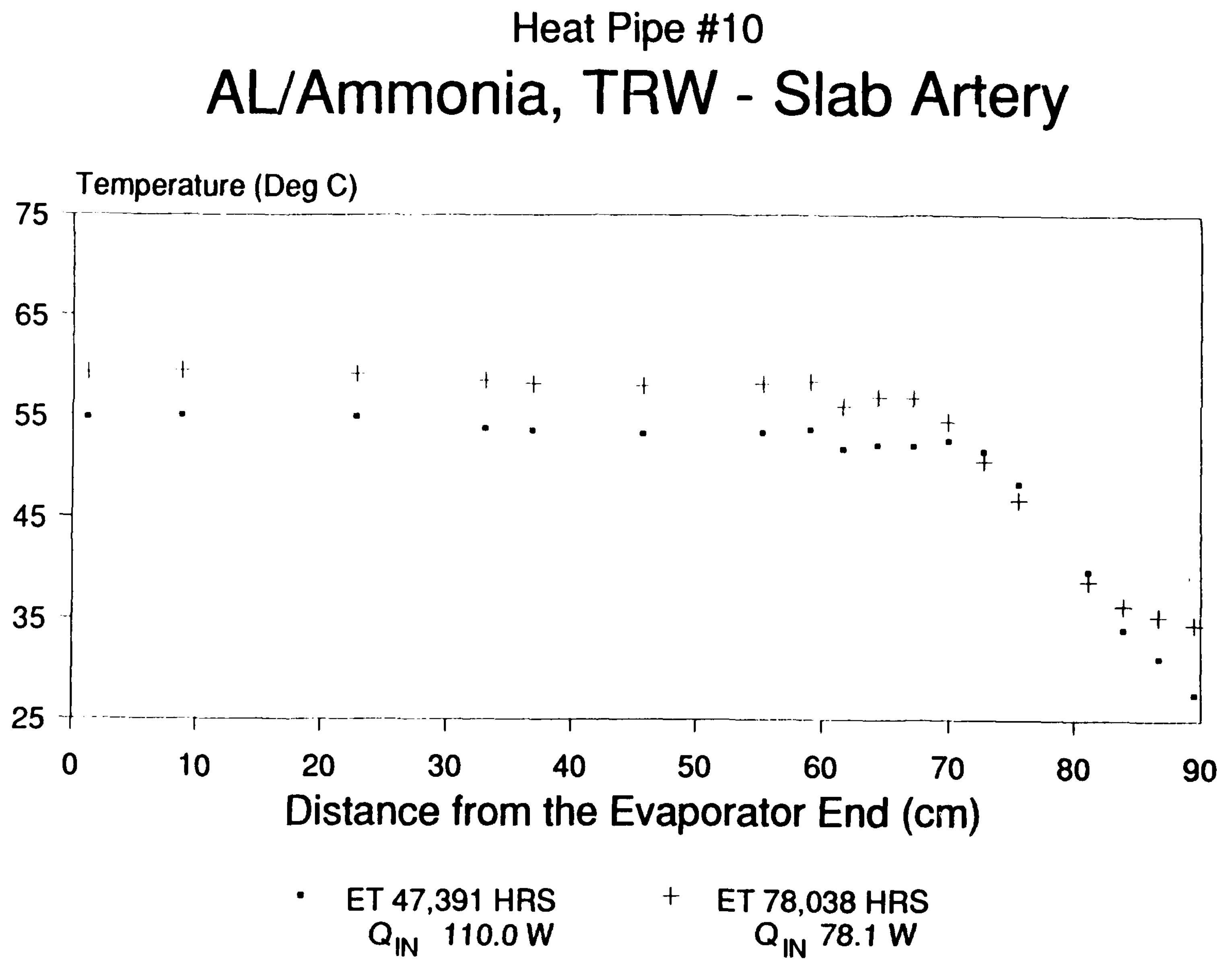


Figure 14. <u>Axial Temperature Profiles of the Low Temperature Heat Pipes #10</u>.

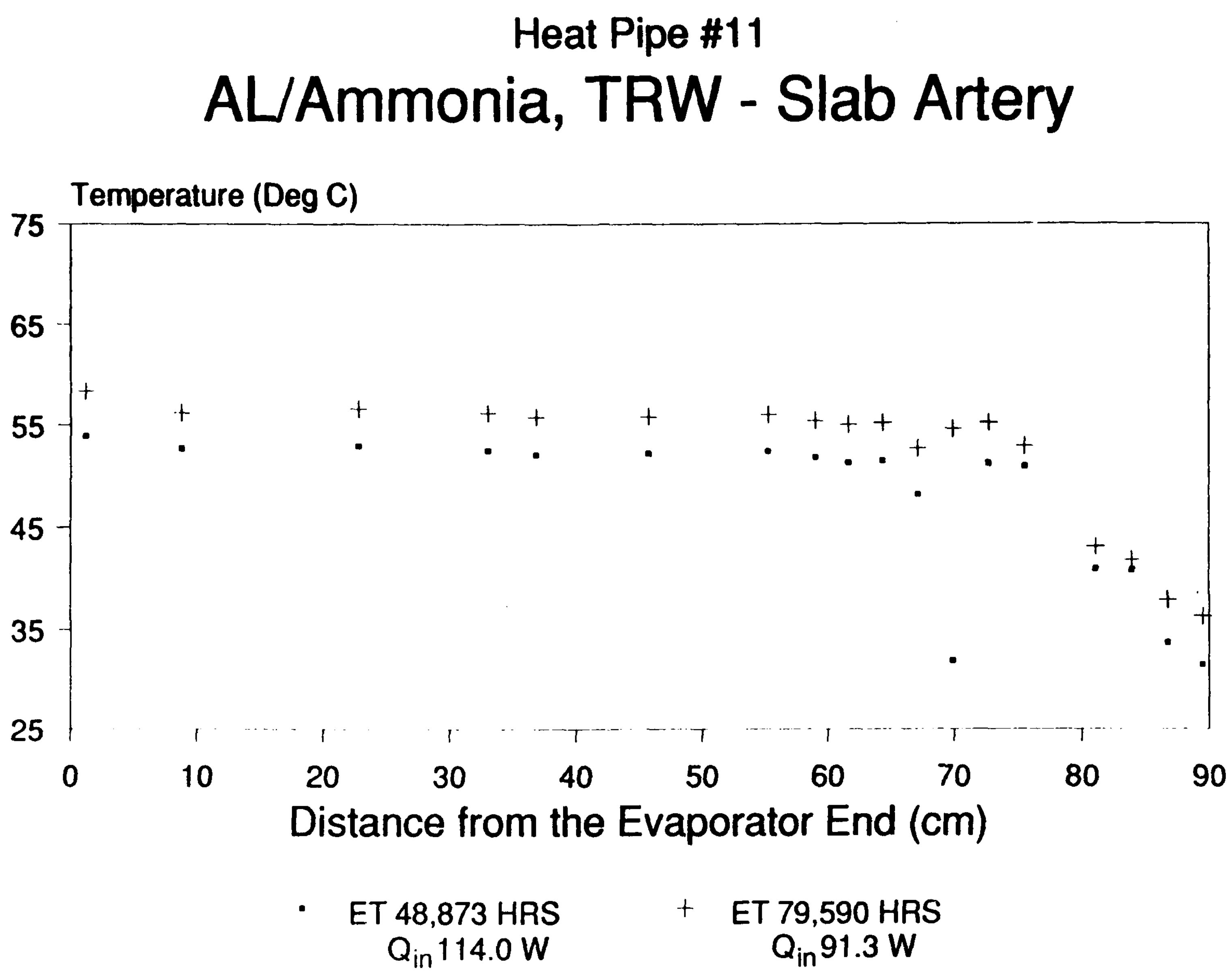


Figure 15. Axial Temperature Profiles of the Low Temperature Heat Pipes #11.

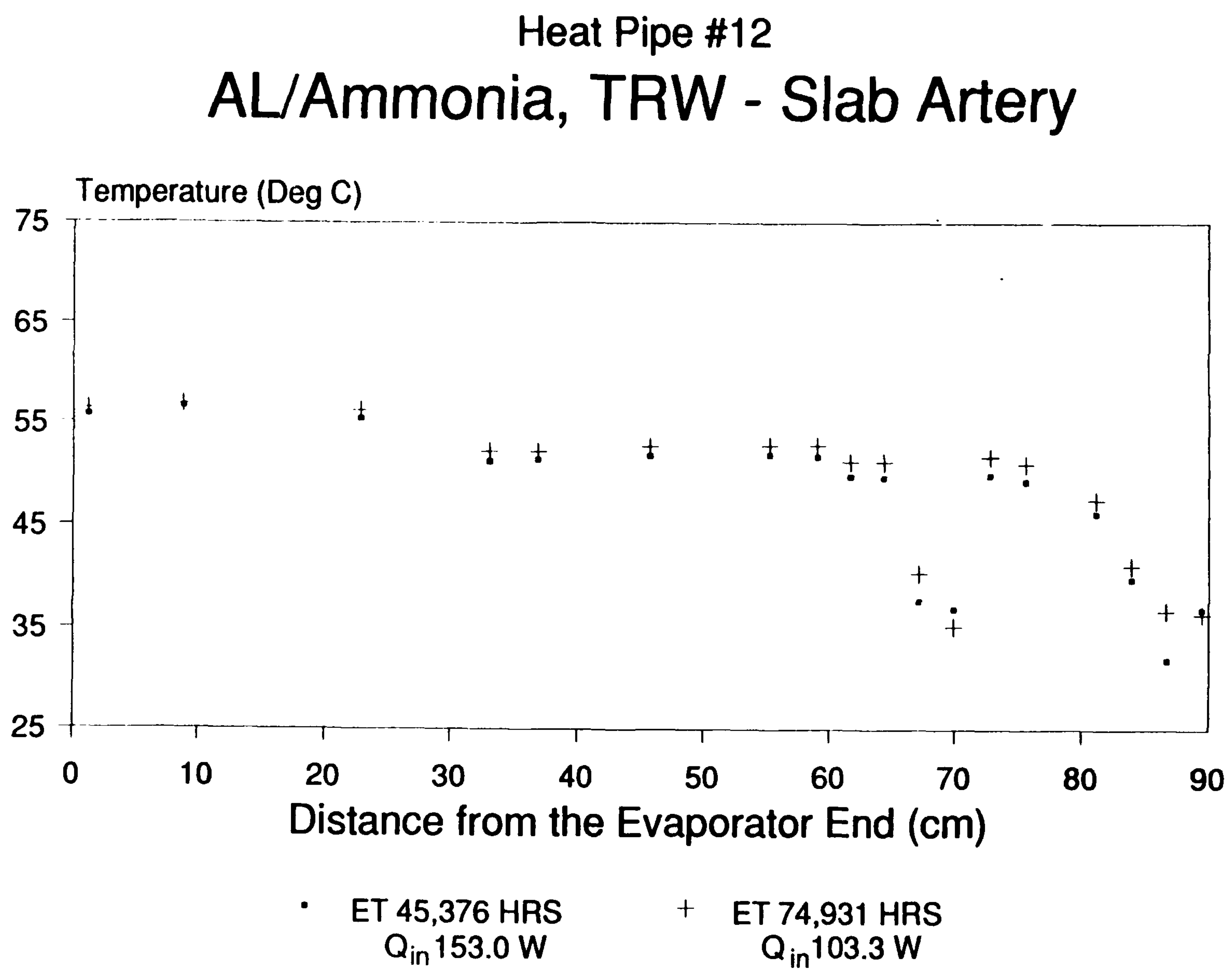


Figure 16. Axial Temperature Profiles of the Low Tempera... Heat Pipes #12.

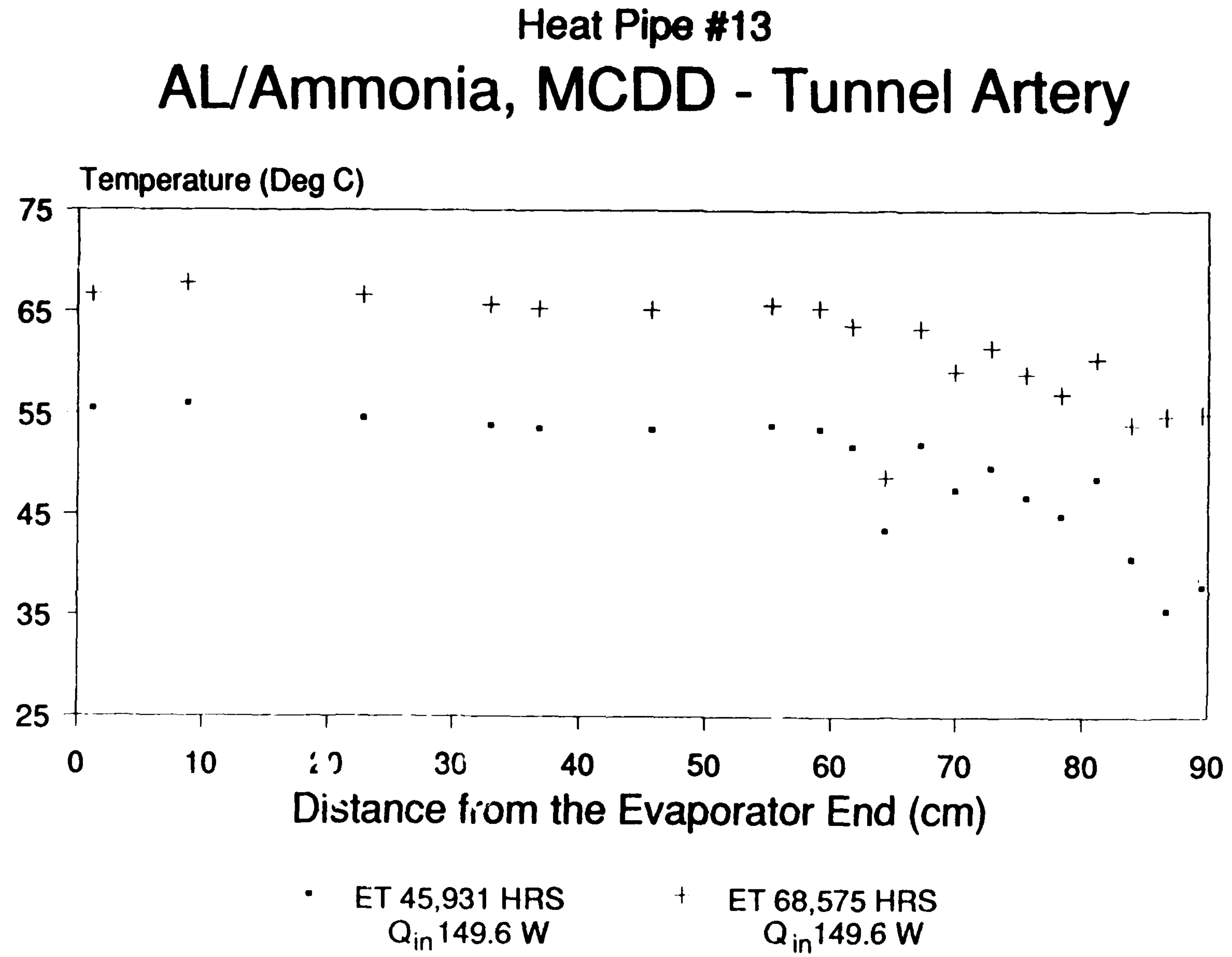


Figure 17. Axial Temperature Profiles of the Low Temperature Heat Pipes #13.

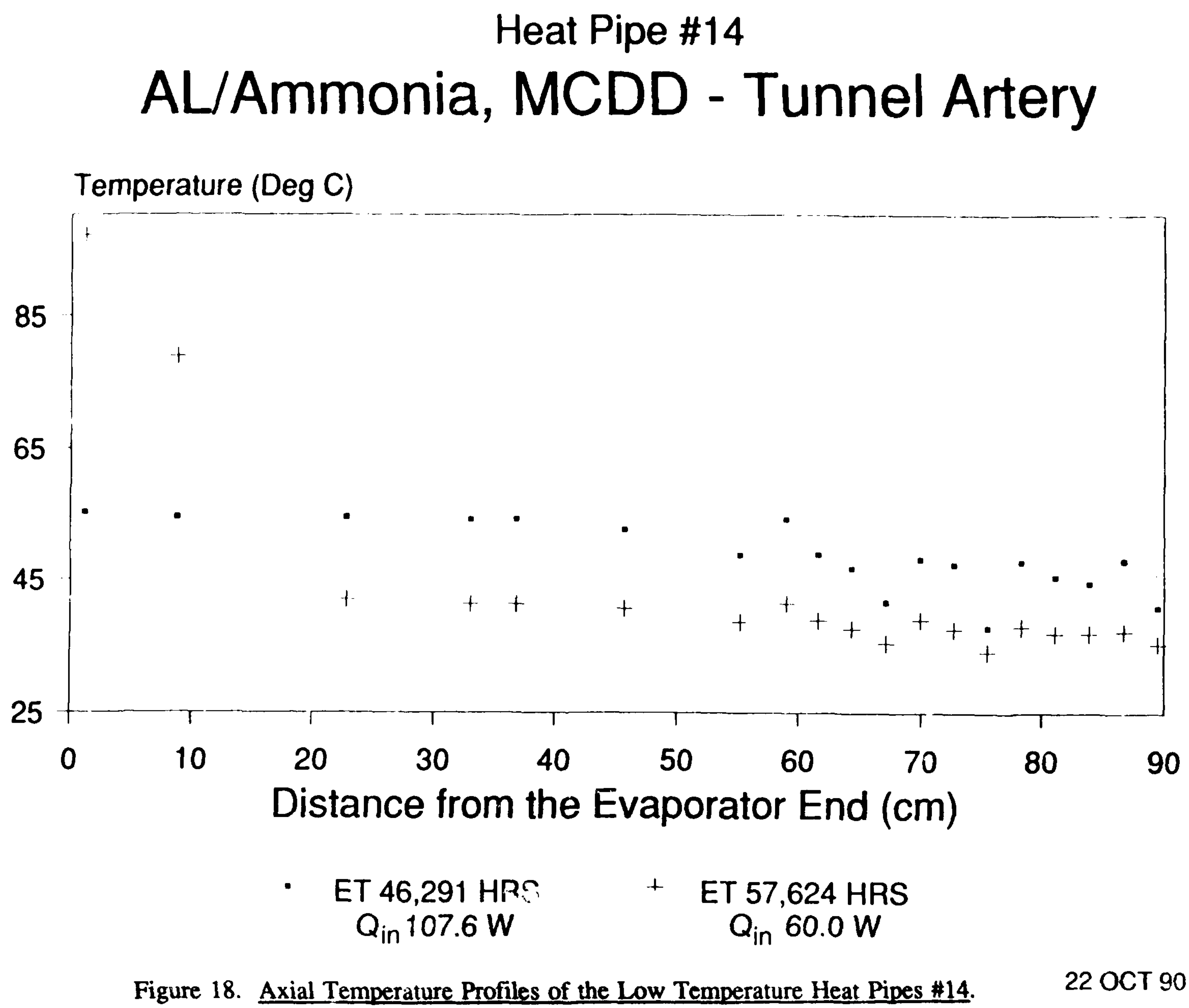


Figure 18. Axial Temperature Profiles of the Low Temperature Heat Pipes #14.

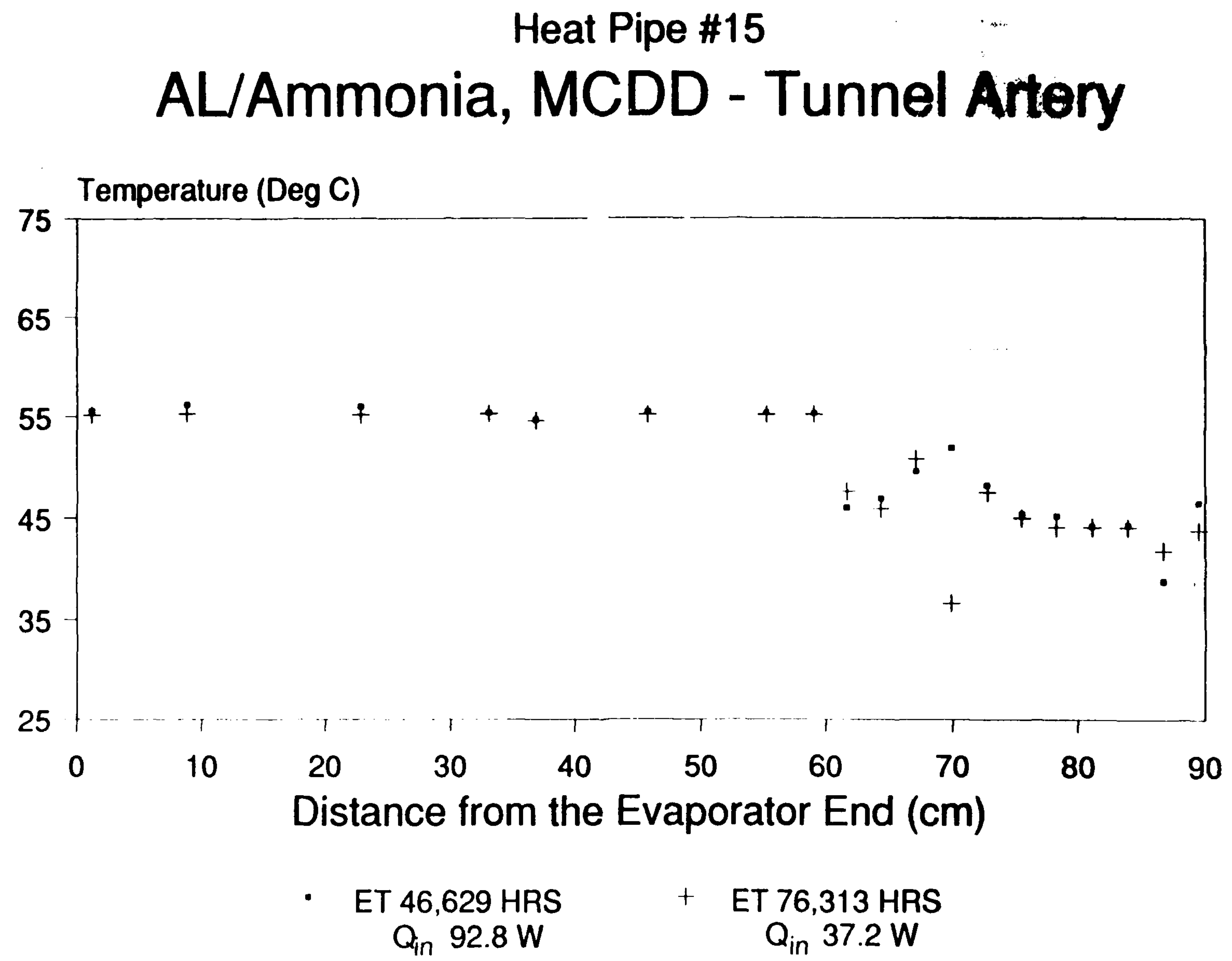


Figure 19. Axial Temperature Profiles of the Low Temperature Heat Pipes #15.

22 OCT 90

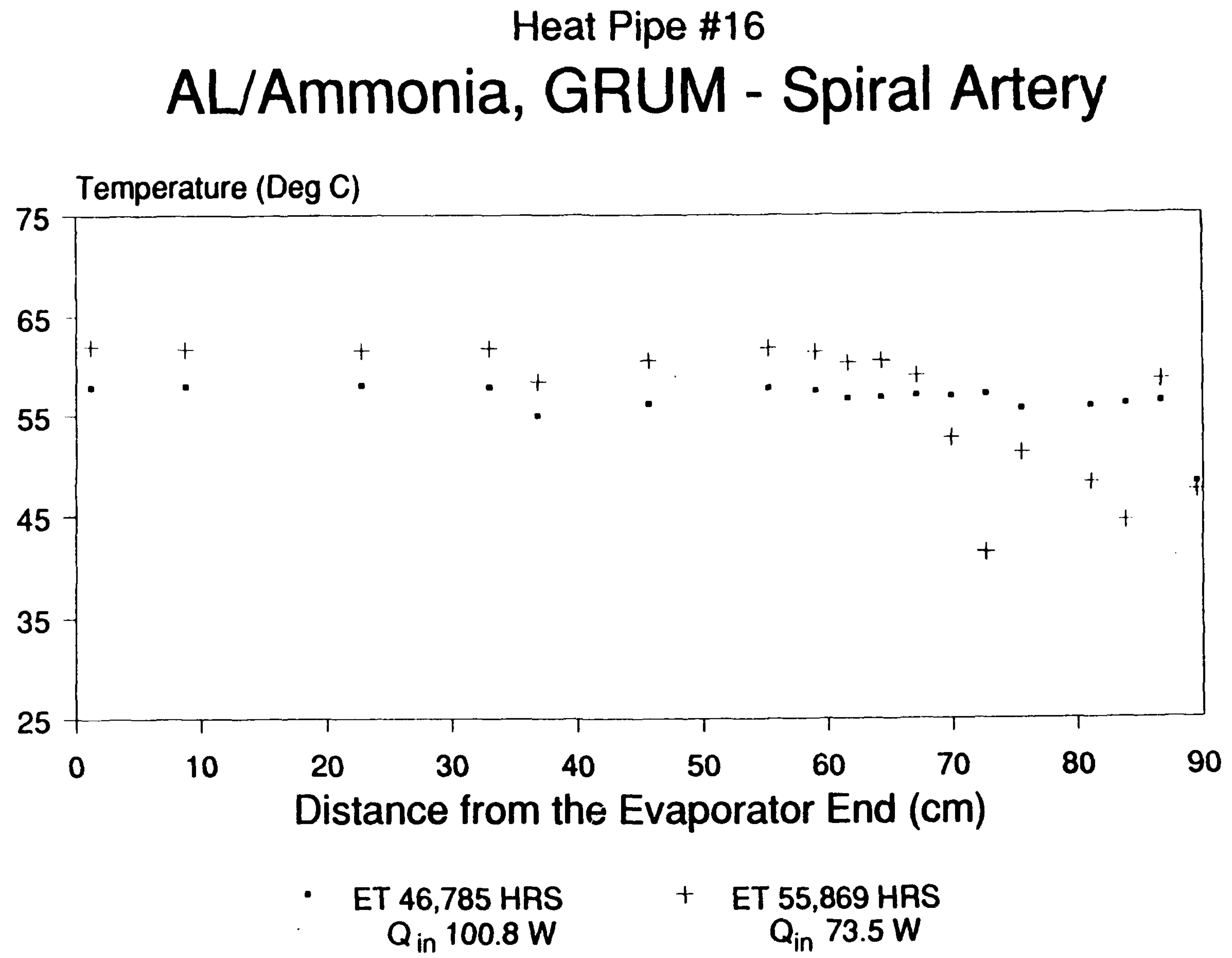


Figure 20. Axial Temperature Profiles of the Low Temperature Heat Pipes #16.

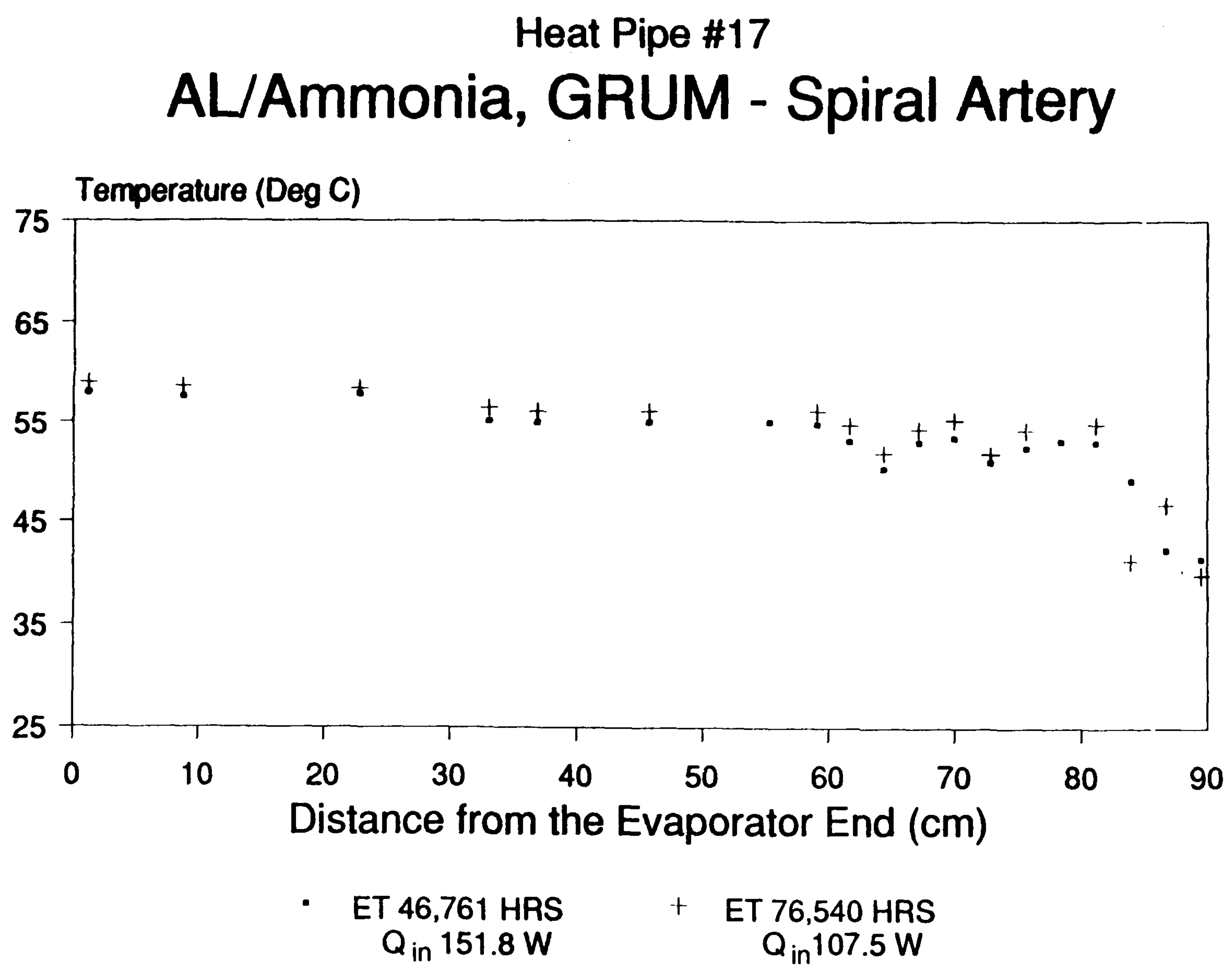


Figure 21. Axial Temperature Profiles of the Low Temperature Heat Pipes #17.

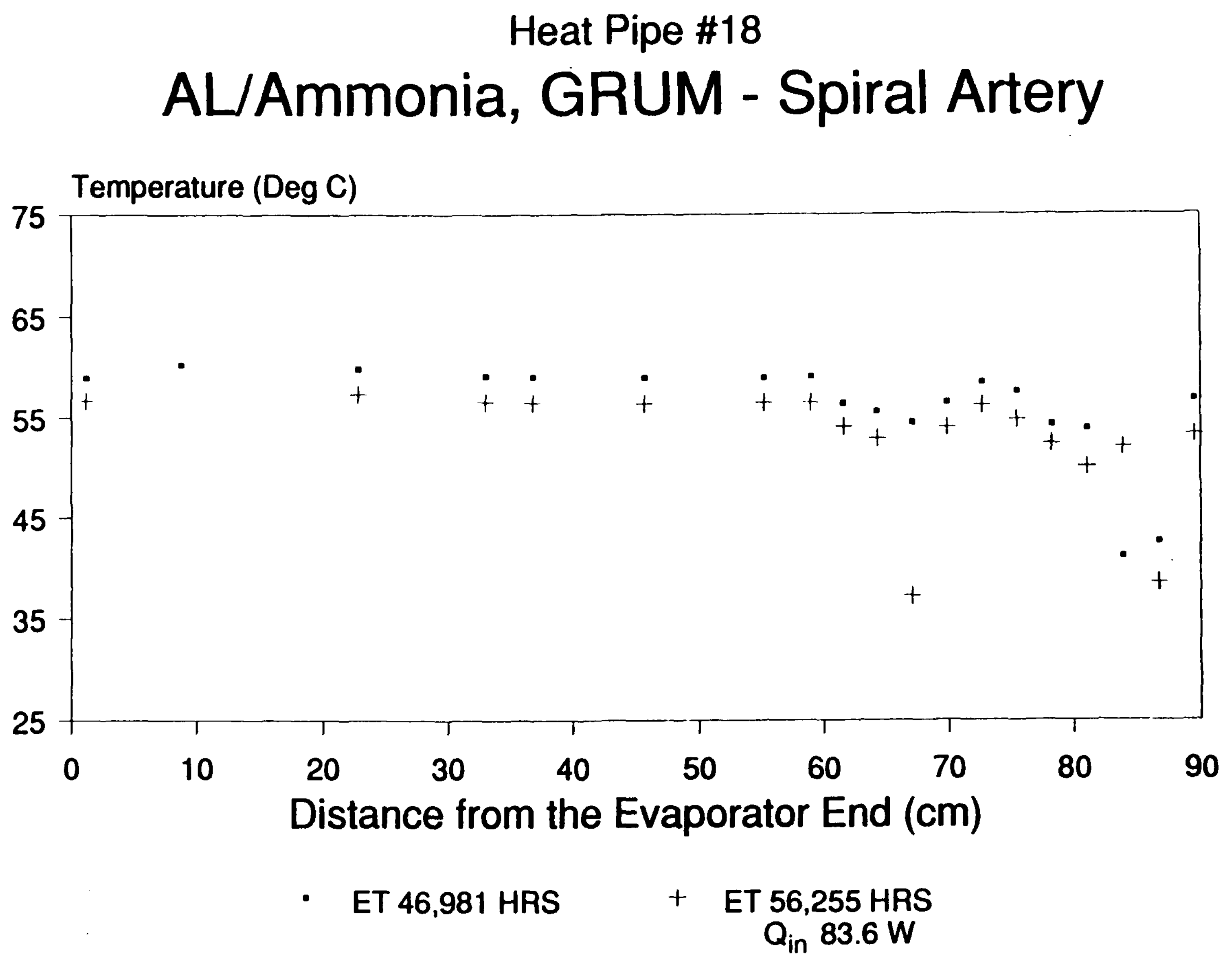


Figure 22. Axial Temperature Profiles of the Low Temperature Heat Pipes #18. 22 OCT 90

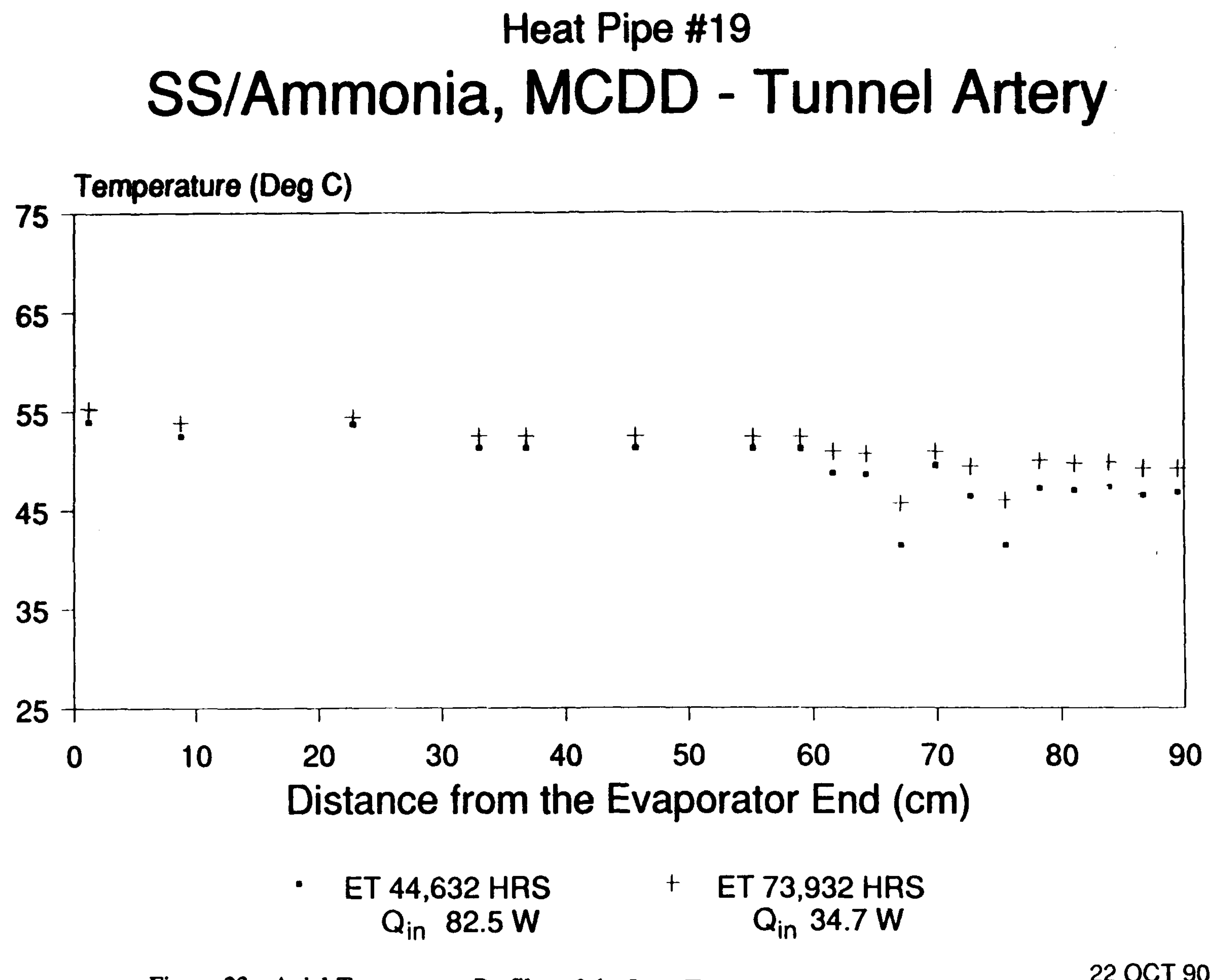


Figure 23. Axial Temperature Profiles of the Low Temperature Heat Pipes #19.

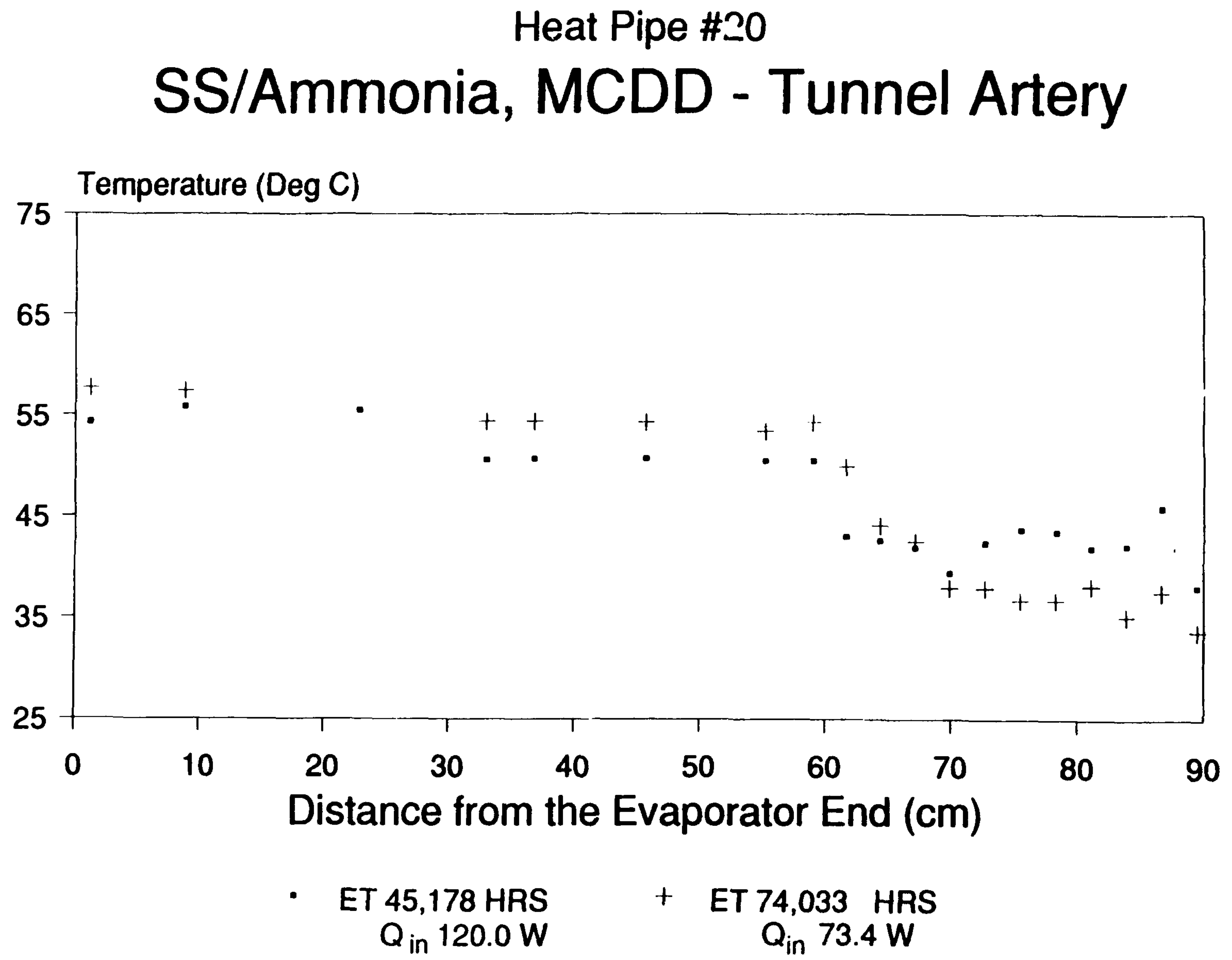


Figure 24. Axial Temperature Profiles of the Low Temperature Heat Pipes #20.

22 OCT 90

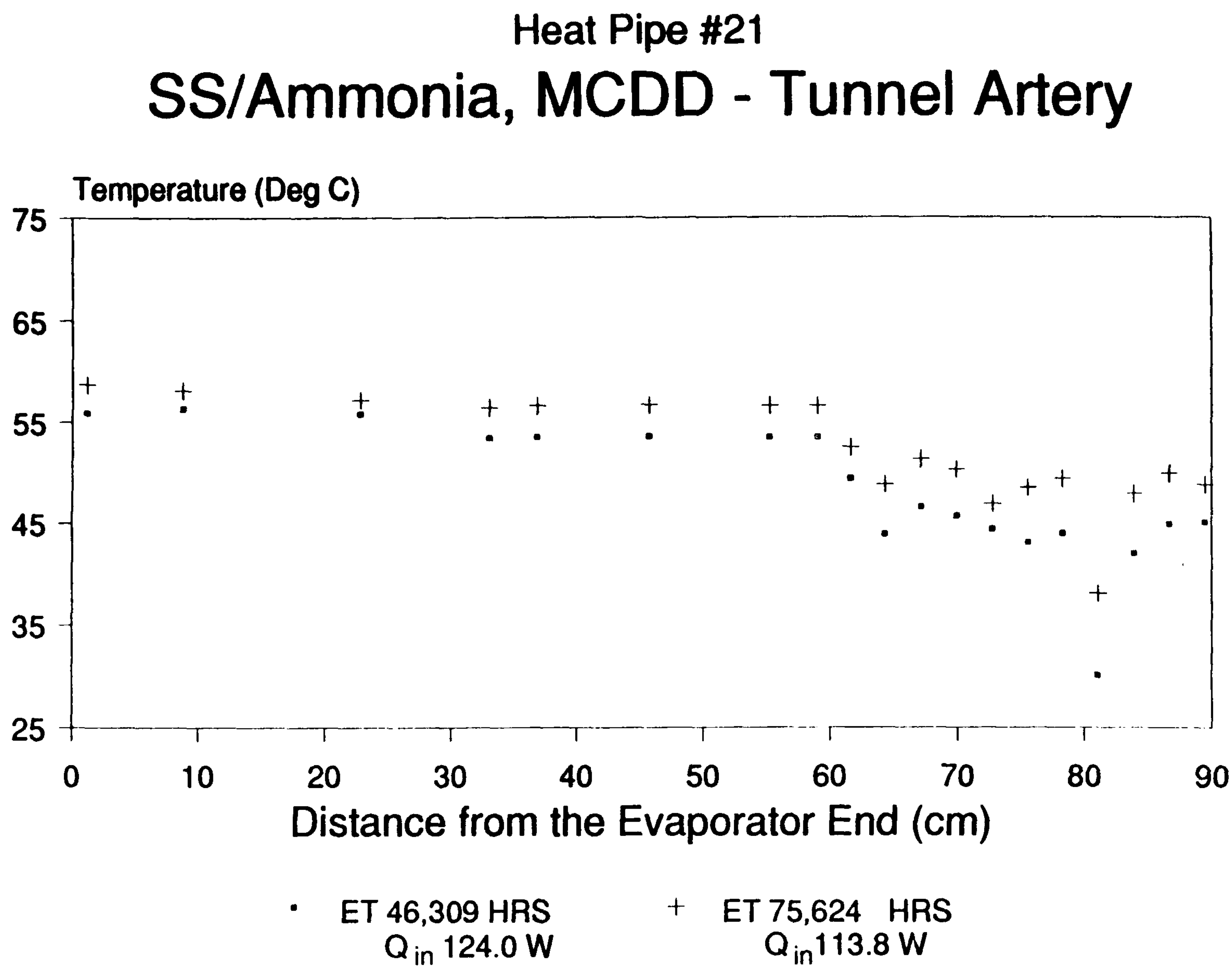
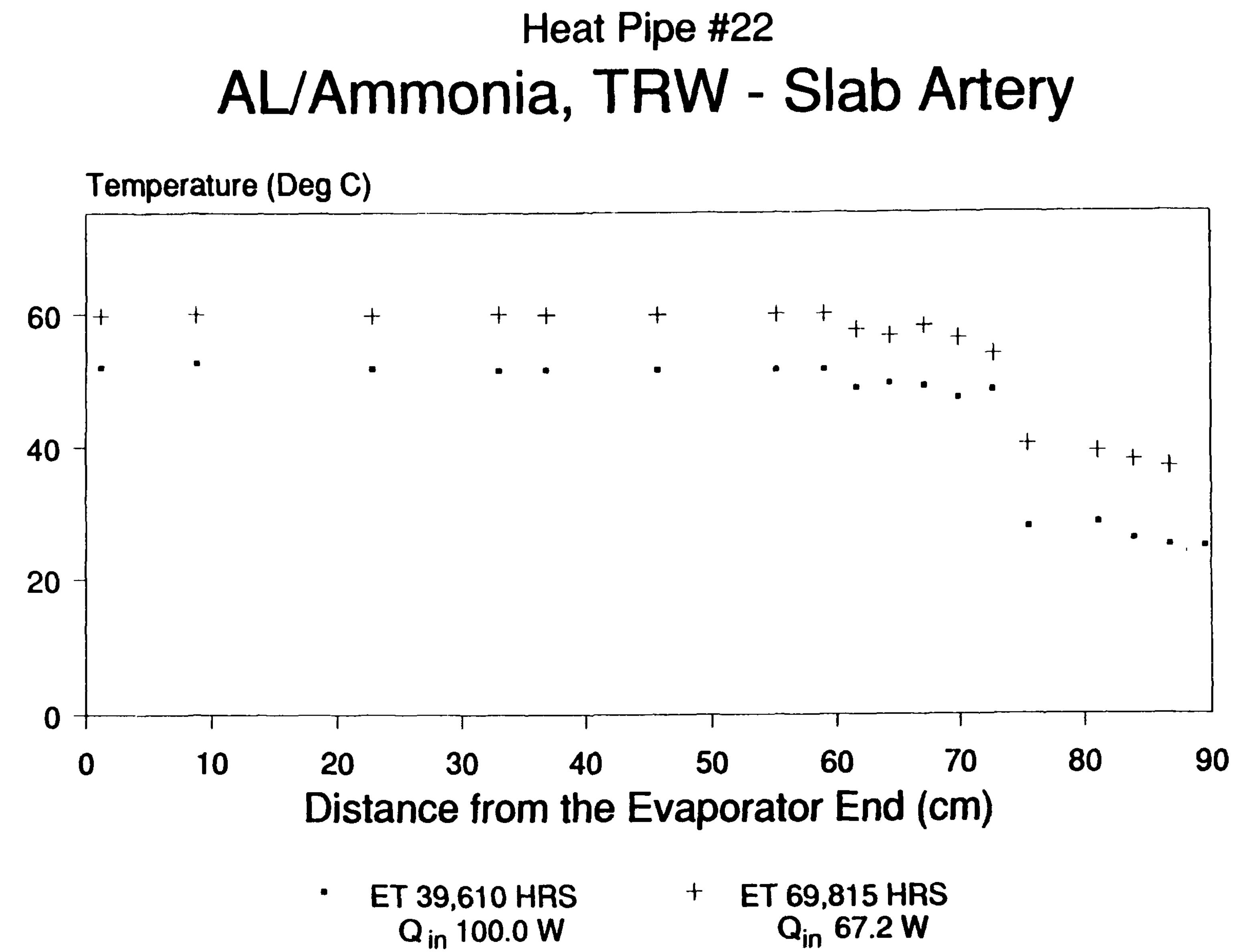


Figure 25. Axial Temperature Profiles of the Low Temperature Heat Pipes #21.

22 OCT 90



22 OCT 90

Figure 26. Axial Temperature Profiles of the Low Temperature Heat Pipes #22.

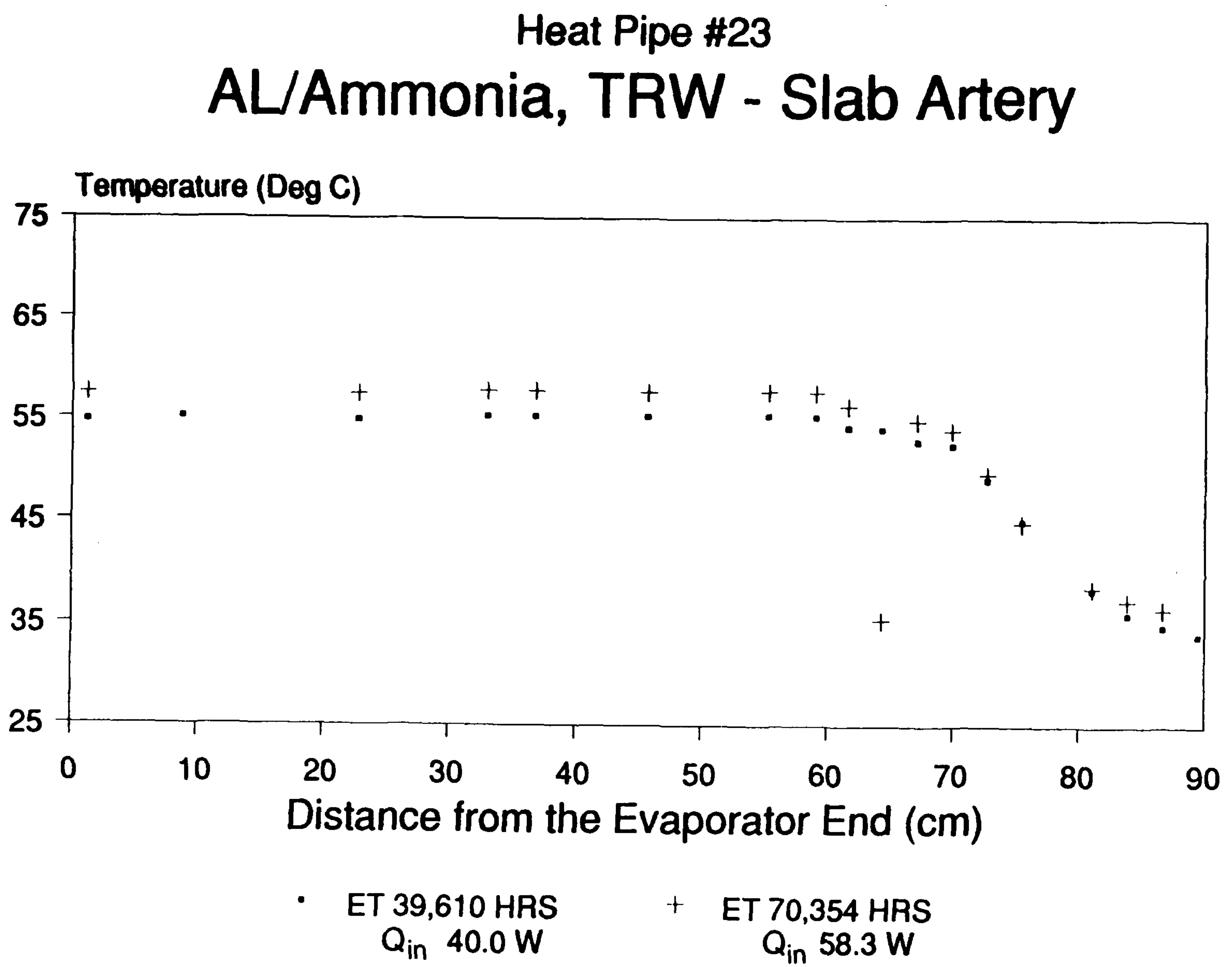


Figure 27. Axial Temperature Profiles of the Low Temperature Heat Pipes #23.

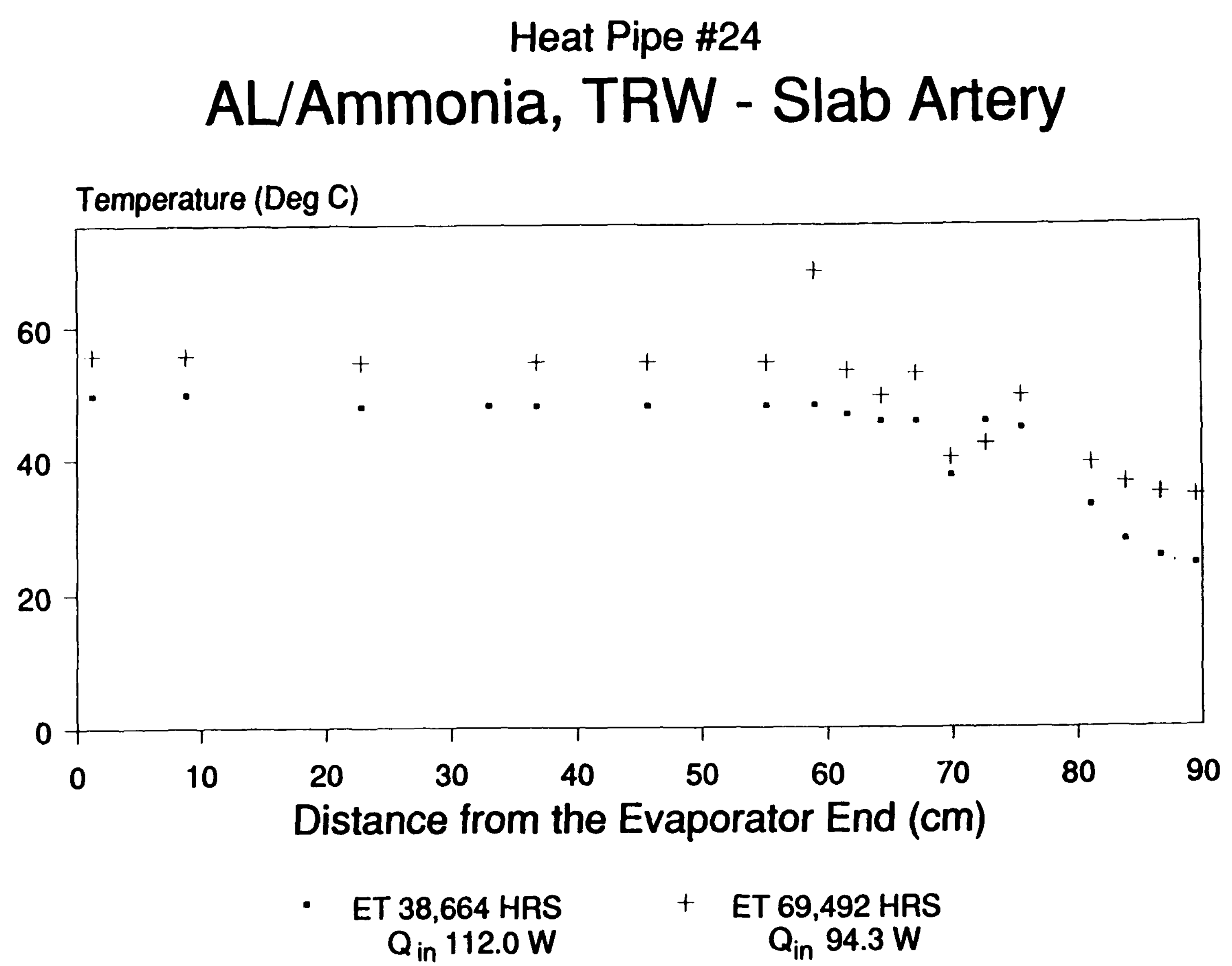


Figure 28. Axial Temperature Profiles of the Low Temperature Heat Pipes #24.

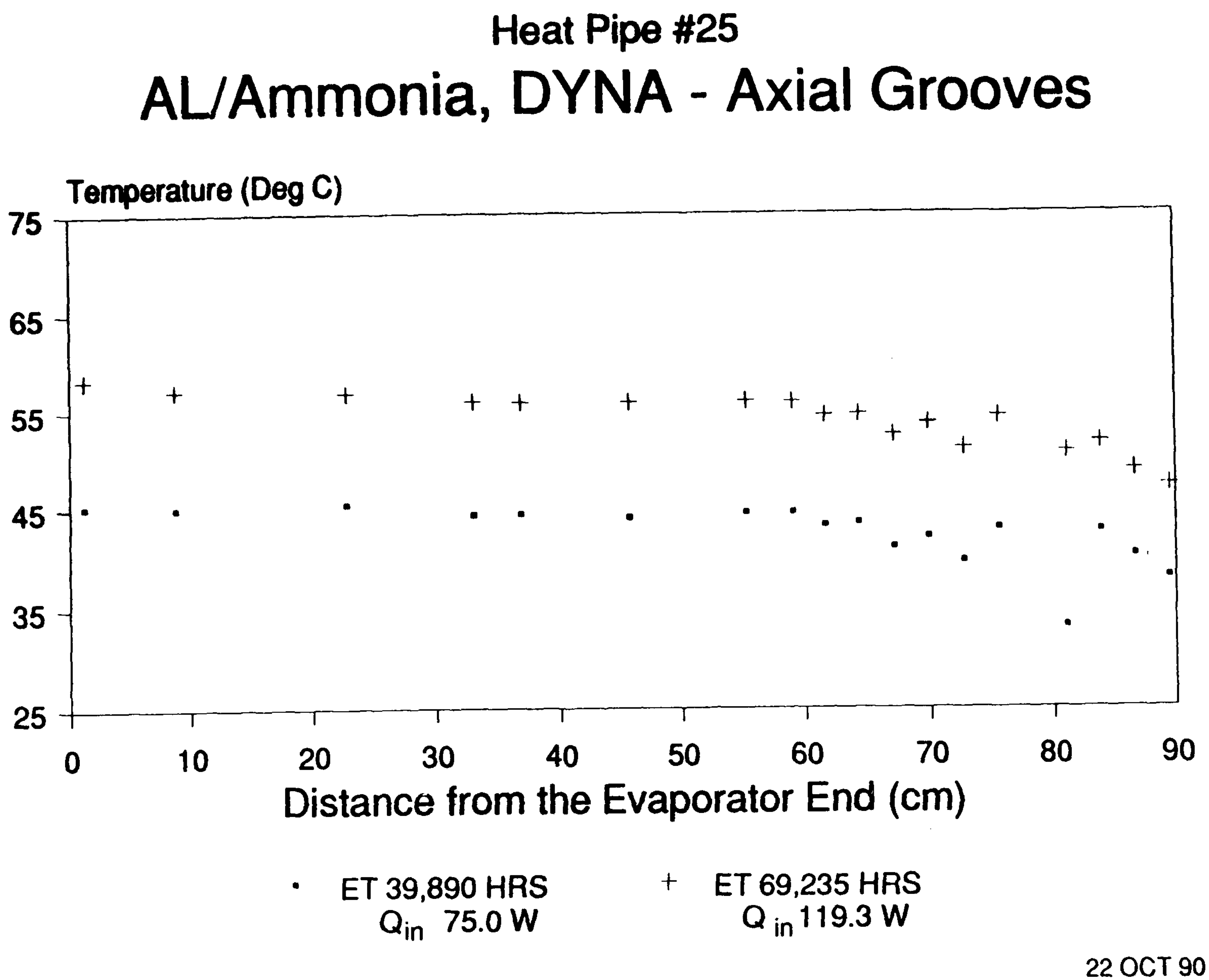


Figure 29. Axial Temperature Profiles of the Low Temperature Heat Pipes #25.

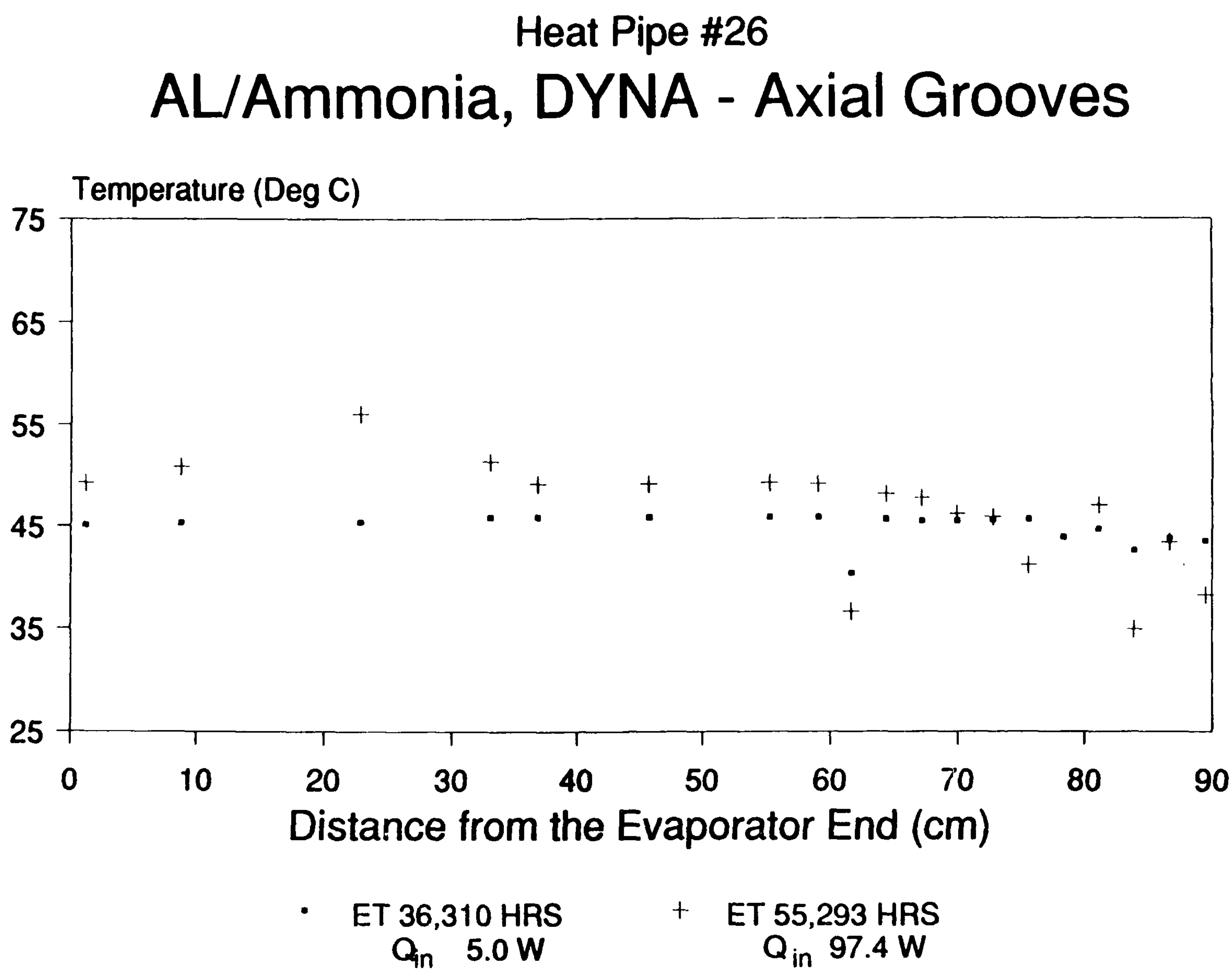


Figure 30. Axial Temperature Profiles of the Low Temperature Heat Pipes #26.

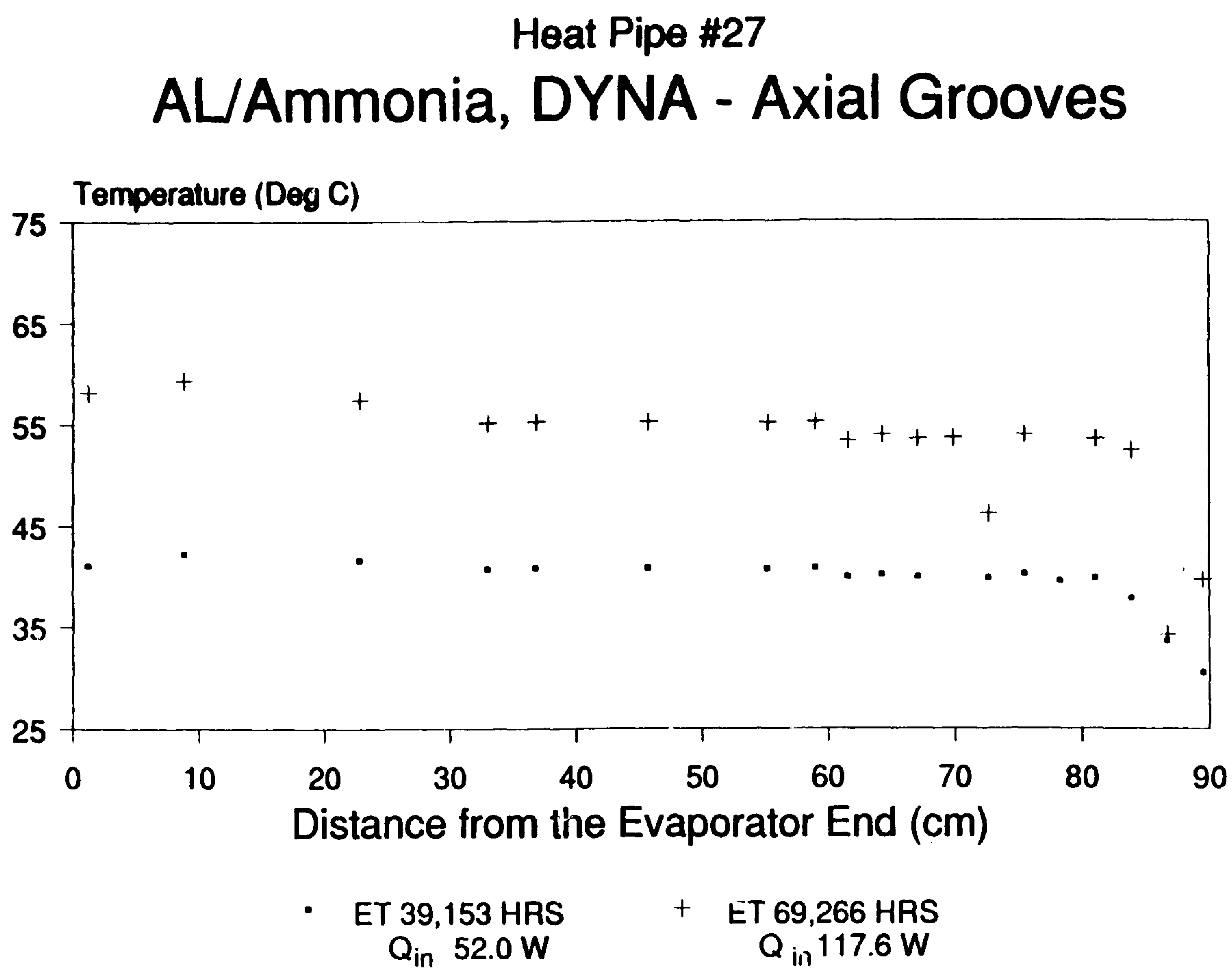


Figure 31. Axial Temperature Profiles of the Low Temperature Heat Pipes #27.

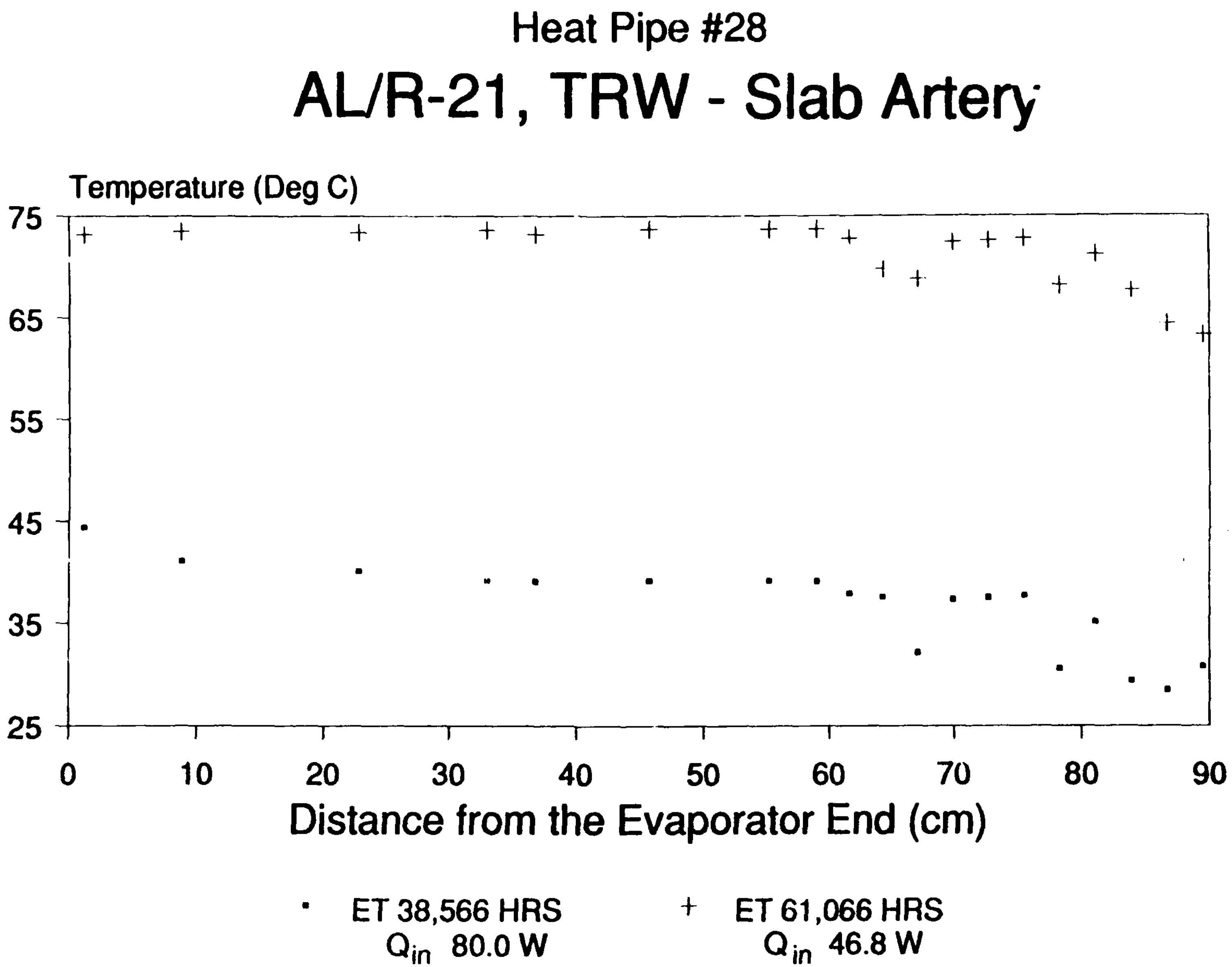


Figure 32. Axial Temperature Profiles of the Low Temperatur~ Heat Pipes #28.

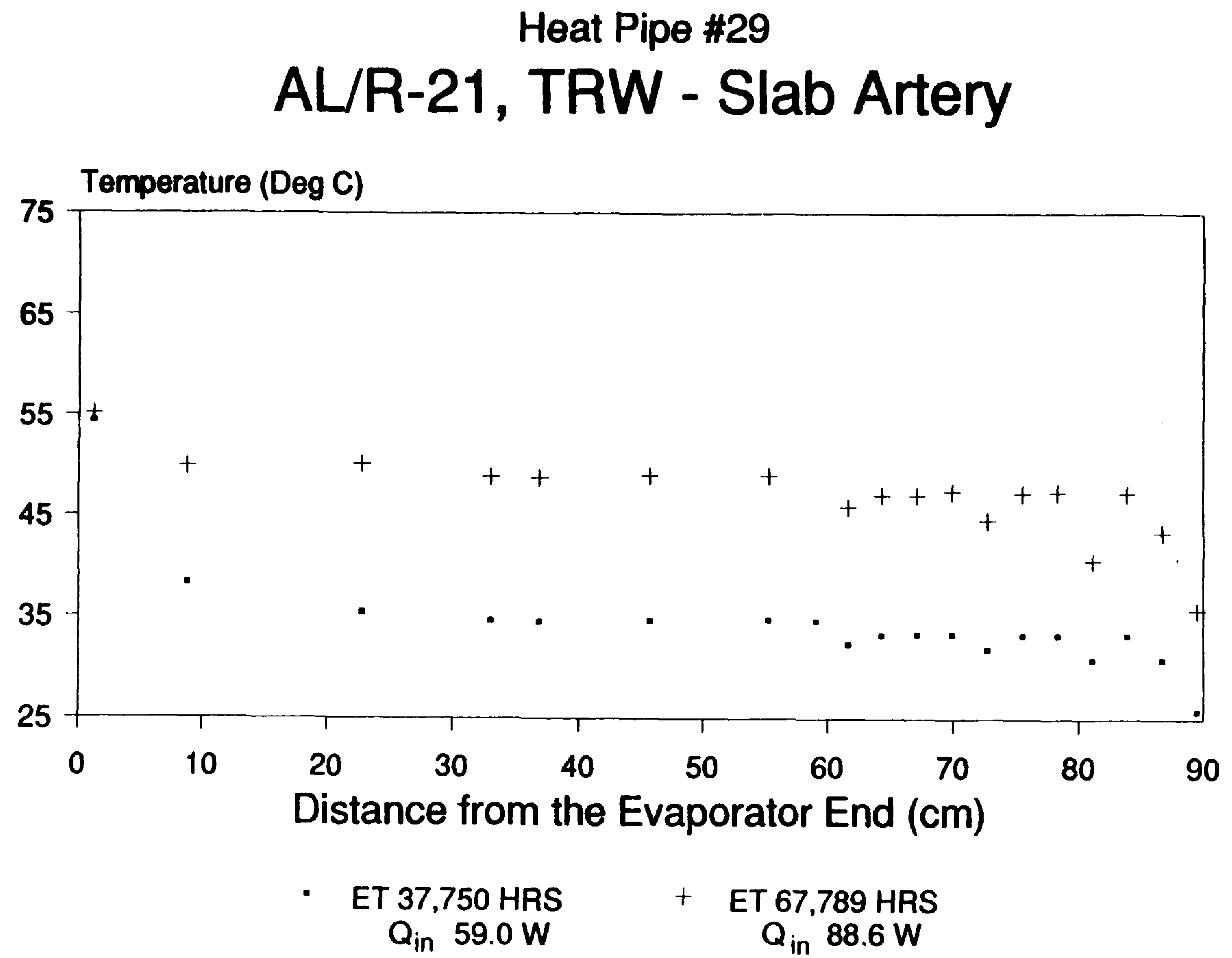


Figure 33. <u>Axial Temperature Profiles of the Low Temperature Heat Pipes #29</u>.

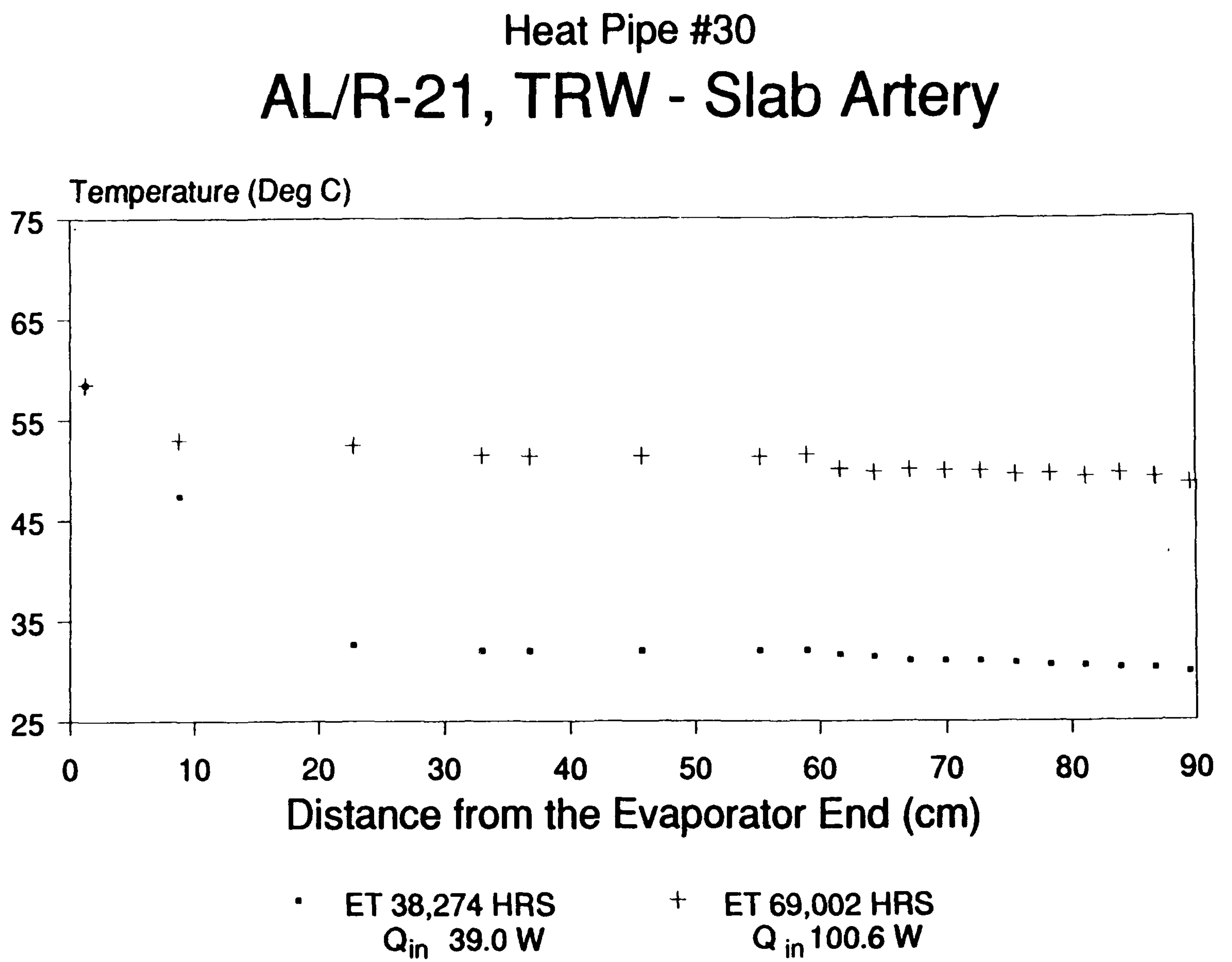


Figure 34. Axial Temperature Profiles of the Low Temperature Heat Pipes #30.

TABLE 4. Low Temperature Heat Pipe Life Test Data: SS Heat Pipes

Performance Parameter	Time * of Data at WRDC	SS/Methanol Heat Pipe No. 1	2	3	4	5	6	7	8	9	SS/Ammonia Heat Pipe No. 19	20	21
Average Power Input Q_{in} [W]	Year 1	100.0	91.0	130.0	32.0	37.0	20.0	30.0	60.0	64.0	83.0	120.0	124.0
	Year 2	128.1	106.4	153.6	61.2	37.4	20.8	30.0	90.0	69.0	81.6	120.0	114.0
	Year 3	80.9	91.0	110.2	---	40.3	25.2	28.0	70.4	66.7	56.7	120.0	124.0
	Year 4	85.0	91.0	71.3	30.8	30.0	25.2	12.35	35.7	58.8	65.3	69.0	94.5
Average Operating Temperature T_{10} [°C]	Year 1	52.0	54.8	55.8	55.8	60.3	50.0	57.5	50.9	54.3	55.1	51.7	55.8
	Year 2	63.5	57.8	59.0	61.9	62.2	51.9	60.5	62.0	57.0	57.1	54.6	55.4
	Year 3	55.6	55.9	58.5	---	65.6	56.5	64.3	62.3	60.6	52.8	60.0	61.9
	Year 4	58.8	56.4	56.4	59.7	56.2	58.9	57.4	56.4	57.9	51.8	54.1	54.2
Temperature Difference end-to-end $\Delta T_{1\text{-}24}$ [°C]	Year 1	5.0	28.1	13.2	29.7	34.6	23.6	31.3	26.5	22.6	8.3	16.2	11.9
	Year 2	6.9	28.5	27.1	32.1	32.9	22.2	31.1	34.9	23.9	8.2	15.8	10.4
	Year 3	5.4	26.5	23.0	---	31.1	21.6	29.5	30.1	22.9	5.5	17.5	10.7
	Year 4	13.1	25.0	25.9	26.3	22.7	25.0	23.0	24.0	21.8	5.7	23.9	8.2

* Data reference Date: Year 1 = 7/18/87; Year 2 = 7/15/88; Year 3 = 7/14/89; Year 4 = 7/16/90

TABLE 5. Low Temperature Heat Pipe Life Test Data: Aluminum Heat Pipes

Performance Parameter	Time * of Data at WRDC	Aluminum/Ammonia Heat Pipe No.								
		10	11	12	13@	14@	15	16	17	18
Average Power Input Q_{in} [W]	Year 1	112.0	110.0	153.0	150.0	106.0	91.0	---	152.0	---
	Year 2	108.3	115.9	156.4	126.0	60.0	85.0	---	148.1	---
	Year 3	99.0	115.9	156.4	80.0	---	78.4	---	135.5	---
	Year 4	76.8	89.1	100.8	---	---	35.2	72.0	108.3	85.8
Average Operating Temperature T_{10} [°C]	Year 1	56.2	52.4	51.1	49.4	55.4	55.5	---	56.4	---
	Year 2	58.7	55.6	55.5	53.2	41.3	55.5	---	59.1	---
	Year 3	61.9	60.9	60.3	49.8	---	60.1	---	62.9	---
	Year 4	57.9	55.4	52.2	---	---	54.6	59.5	56.1	56.7
Temperature Difference end-to-end ΔT_{1-24} [°C]	Year 1	30.4	23.3	23.2	23.6	13.4	12.4	---	22.3	---
	Year 2	28.7	23.8	23.0	10.4	61.7	10.7	---	22.8	---
	Year 3	28.1	23.3	23.1	8.4	---	10.4	---	22.6	---
	Year 4	24.8	21.8	19.6	---	---	11.5	17.5	19.4	3.4

@ $\Delta T > 30°C$ observed and hence the test discontinued

*Data reference Date: Year 1 = 7/18/87; Year 2 = 7/15/88; Year 3 = 7/14/89; Year 4 = 7/16/90

TABLE 5. Low Temperature Heat Pipe Life Test Data: Aluminum Heat Pipes (continued)

Performance Parameter	Time * of Data at WRDC	Aluminum/Ammonia Heat Pipe No.						Aluminum / R-21 Heat Pipe No.		
		22	23	24	25	26	27	28@	29	30
Average Power Input Q_{in} [W]	Year 1	100.0	37.0	114.0	128.0	14.0	83.0	83.0	57.0	39.0
	Year 2	71.4	58.8	130.2	151.8	---	85.0	95.2	80.0	38.5
	Year 3	95.0	58.8	130.2	100.8	---	69.0	46.8	69.0	35.5
	Year 4	60.0	52.0	93.6	120.9	91.8	120.0	---	91.8	48.0
Average Operating Temperature T_{10} [°C]	Year 1	56.2	53.2	53.6	51.5	45.3	43.4	63.7	41.2	33.6
	Year 2	59.0	52.4	56.2	55.2	---	45.7	53.8	41.3	36.8
	Year 3	60.7	57.5	61.4	51.4	---	47.0	72.0	45.5	40.9
	Year 4	59.2	57.6	54.6	55.9	48.4	55.3	---	49.1	43.1
Temperature Difference end-to-end ΔT_{1-24} [°C]	Year 1	29.7	41.4	28.4	9.6	13.3	31.6	6.8	15.5	28.1
	Year 2	29.7	22.9	28.4	11.3	---	23.9	11.6	13.8	25.8
	Year 3	25.7	23.1	27.9	8.2	---	12.5	10.1	15.3	18.1
	Year 4	22.8	20.7	22.0	11.1	8.6	18.3	---	25.4	18.0

@ $\Delta T > 30°C$ observed and hence the test discontinued

* Data reference Date: Year 1 = 7/18/87; Year 2 = 7/15/88; Year 3 = 7/14/89; Year 4 = 7/16/90

SECTION III

HIGH TEMPERATURE HEAT PIPE STATIONS

3.1 OBJECTIVES AND SCOPE OF THE LIFE TEST

The objectives and scope of the high temperature heat pipe life test are as follows:

1) Recommission the available (six total) vertical test stands in the newly extended Thermal Laboratory facilities.
2) Upgrade the test stands and data acquisition systems as needed and maintain them in working condition at all times.
3) Improve the heater power measurement such that the Fluke data logger could record the power input to each pipe along with the temperature data.
4) Conduct periodical health check by monitoring the temperature profiles and report status.
5) Record pertinent test data, such as temperature profiles, power input, and temperature drop for all the stands on a monthly basis.
6) Accumulate envelope material to working fluid corrosion compatibility life data on the Inconel 617 and SS304 with sodium, and titanium with potassium systems.

3.2 DESCRIPTION OF THE TEST STAND

The vertical test stands are self-contained test equipment containing a vacion vacuum pump, pump power control unit, water cooled (annular chamber) vacuum chamber with quartz window and feed-through, low voltage high current power supply, set-point temperature controller, and turbo molecular vacuum pump hook up - all of these assembled in a vertical rack. A view of the front of these stands is seen in Figure 35. The construction and assembly details of each of the test chambers are the same. Figure 36 shows the heat pipe mounting, current feed through, shield and cooling coil details of the vacuum chamber. Demineralized water circulates through the coils wrapped around the chamber and through the annular space in the chamber wall. A quartz window helps to see the condenser end of the heat pipe. A magnetically operated shutter covers the glass window from the inside such that the window is protected from overheating.

Figure 35. A View of the High Temperature Heat Pipe "Vertical Stands".

HEAT PIPE LIFE TEST FACILITY

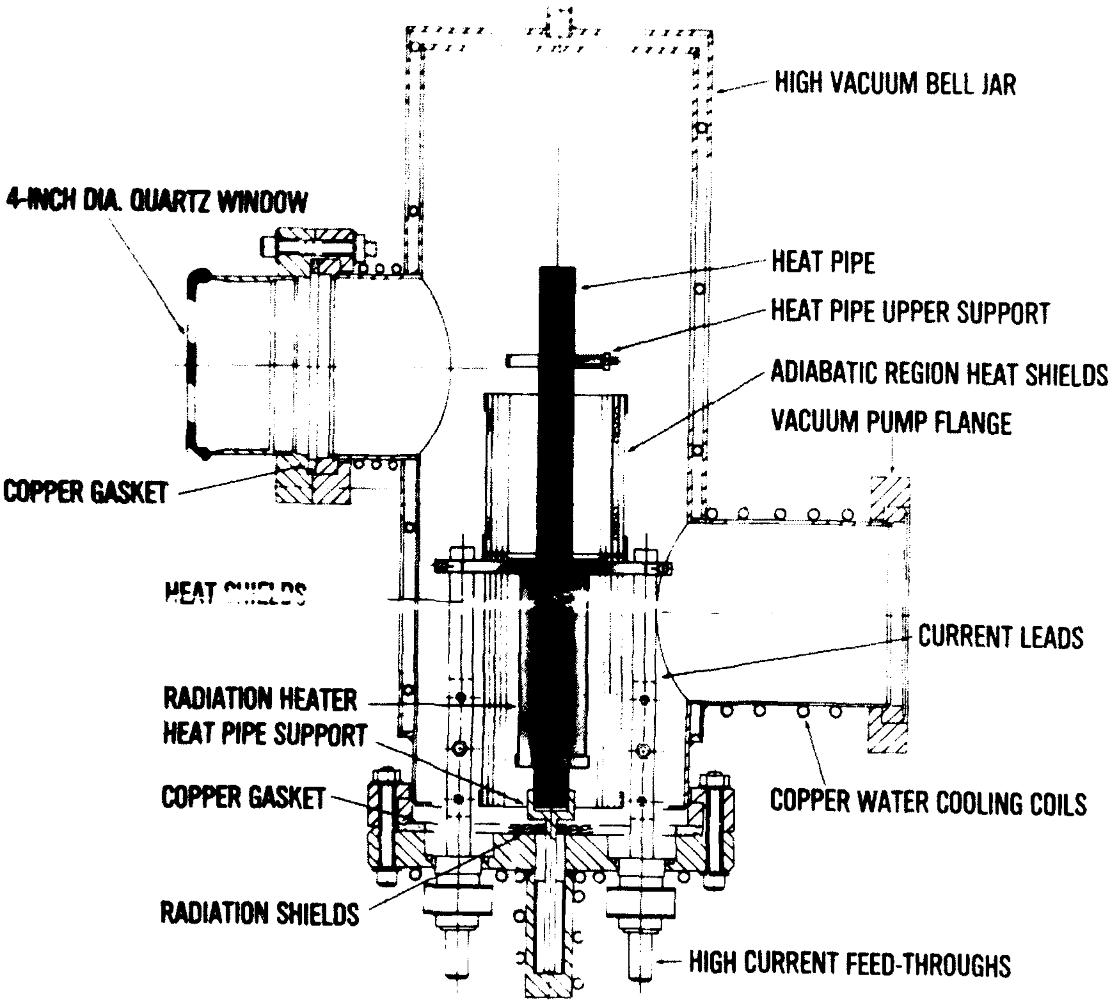


Figure 36. <u>Cross-Sectional View of the Test Chamber.</u>

Protective Interlocks: The heater power input will be shut down automatically if any of the following situations are encountered:

1) Loss of vacuum in the chamber
2) Loss of cooling water circuit (mercury pressure switch set at 5 psig; normal pressure is 30 psig)
3) High or low temperature limit is crossed
4) Power outage and restart

Correction of the fault and manual resetting are necessary to restart the tests.

Heat Pipes Under Test: The physical and design details of the five high temperature heat pipes undergoing life tests are shown in Figure 37 through 41. Five chomel-alumel thermocouples are mounted on each heat pipe out of which one acts as a control thermocouple. The heat pipes are heated by radiative coupling from tantalum heaters. Two copper-constantan thermocouples monitor the cooling water inlet and outlet temperatures. Vertical stand #6 is operational but no heat pipe is installed in this stand.

3.3 DATA ACQUISITION

The data acquisition system consists of a data logger of the type Fluke 2280A and a personal computer. Axial temperatures, power input to the heater, and coolant temperatures from all five stands are constantly scanned by the data logger. The data currently scanned are compared with the data of the previous scan. If the temperature profile at any location changed drastically, then the computer prints out an alarm message.

3.4 LIFE TEST DATA

The test data are gathered once a month and compiled in a monthly report as in Table 6. A log book maintained with each stand also contains this monthly data[7]. The pipes have completed 24,000-37,000 hours as of September 1990. A 4-year summary of data is given in Table 7.

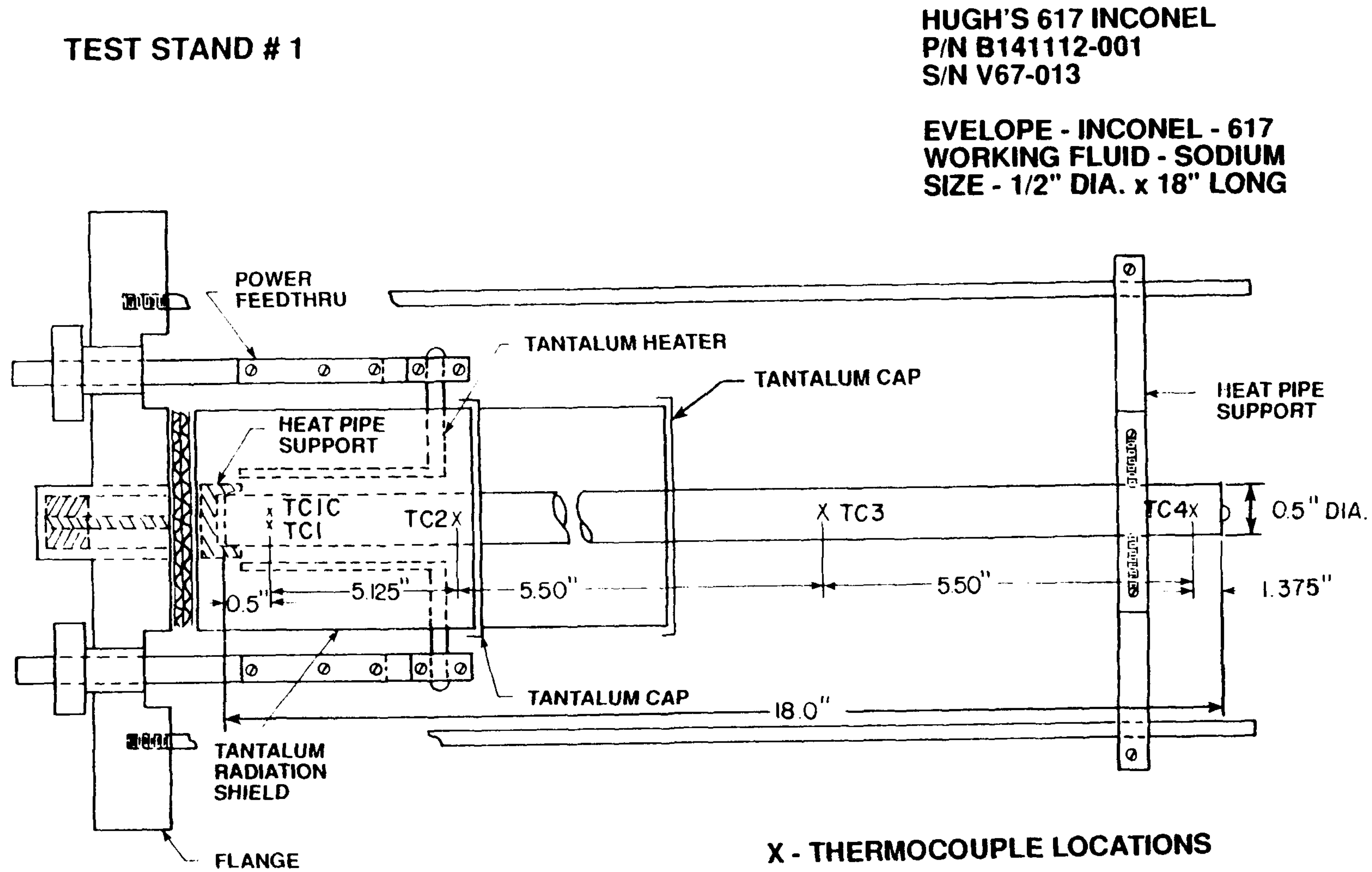


Figure 37. Inconel 617-Sodium Heat Pipe in Stand 1.

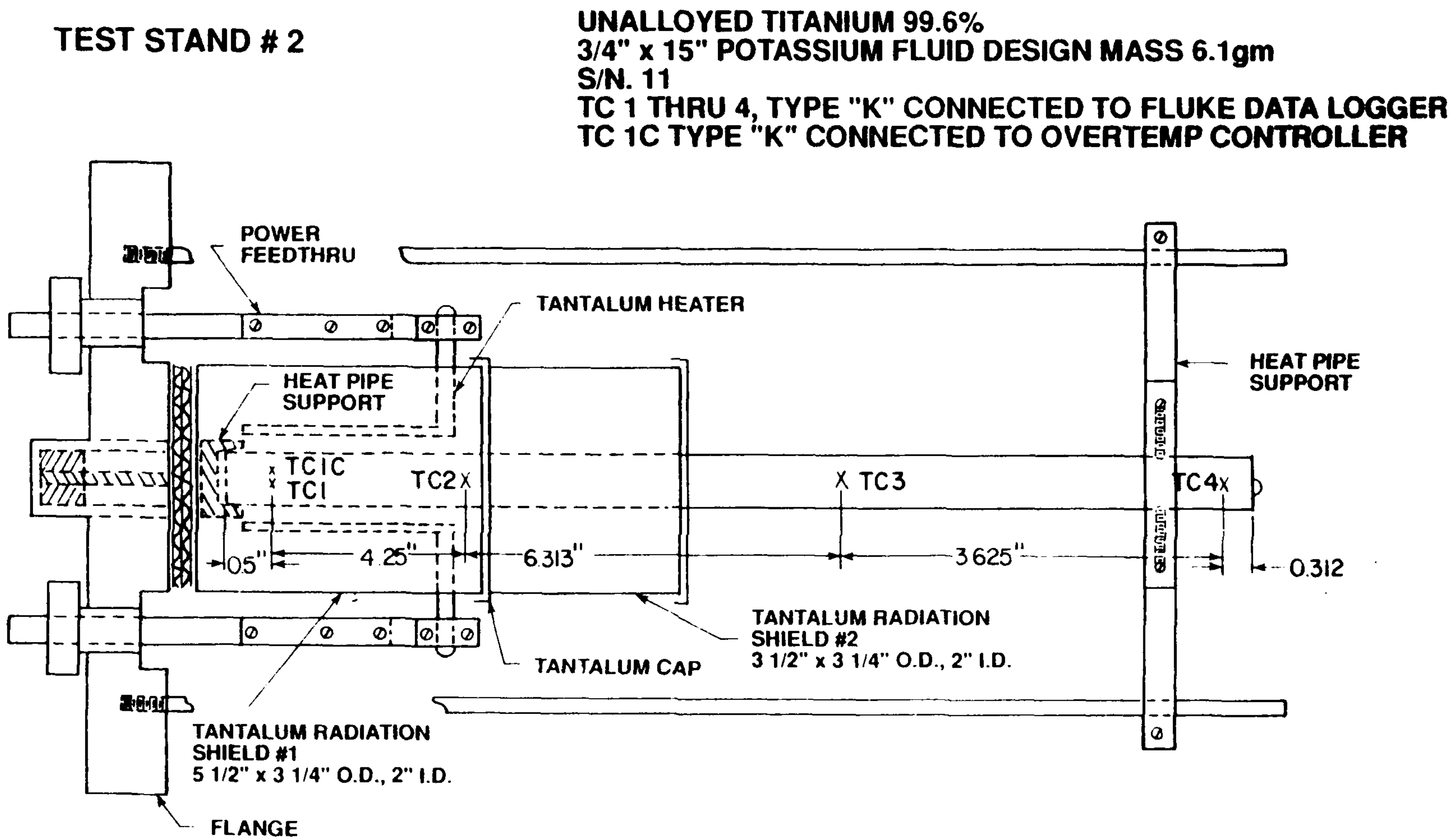


Figure 38. Titanium-Potassium Heat Pipe in Stand 2.

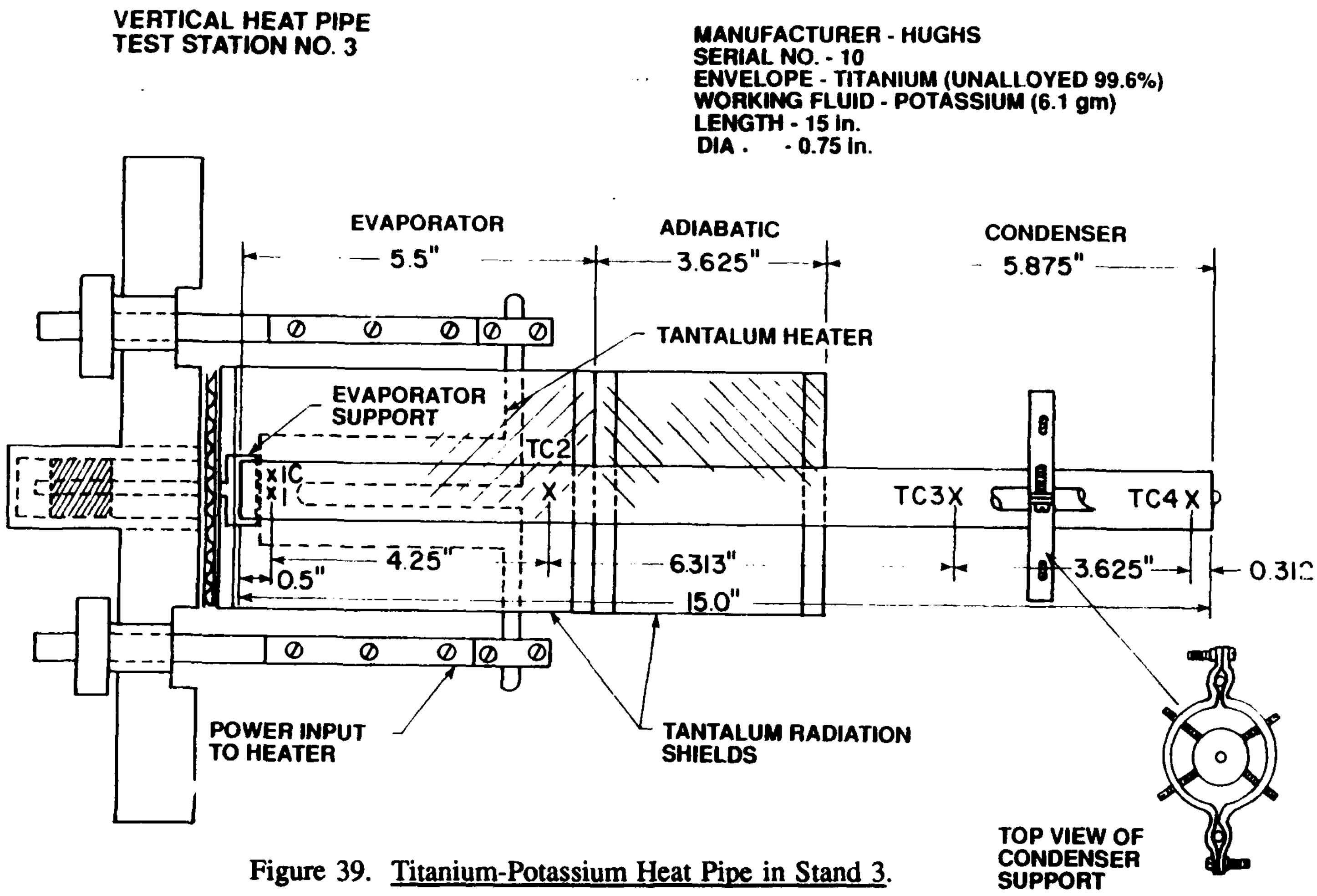
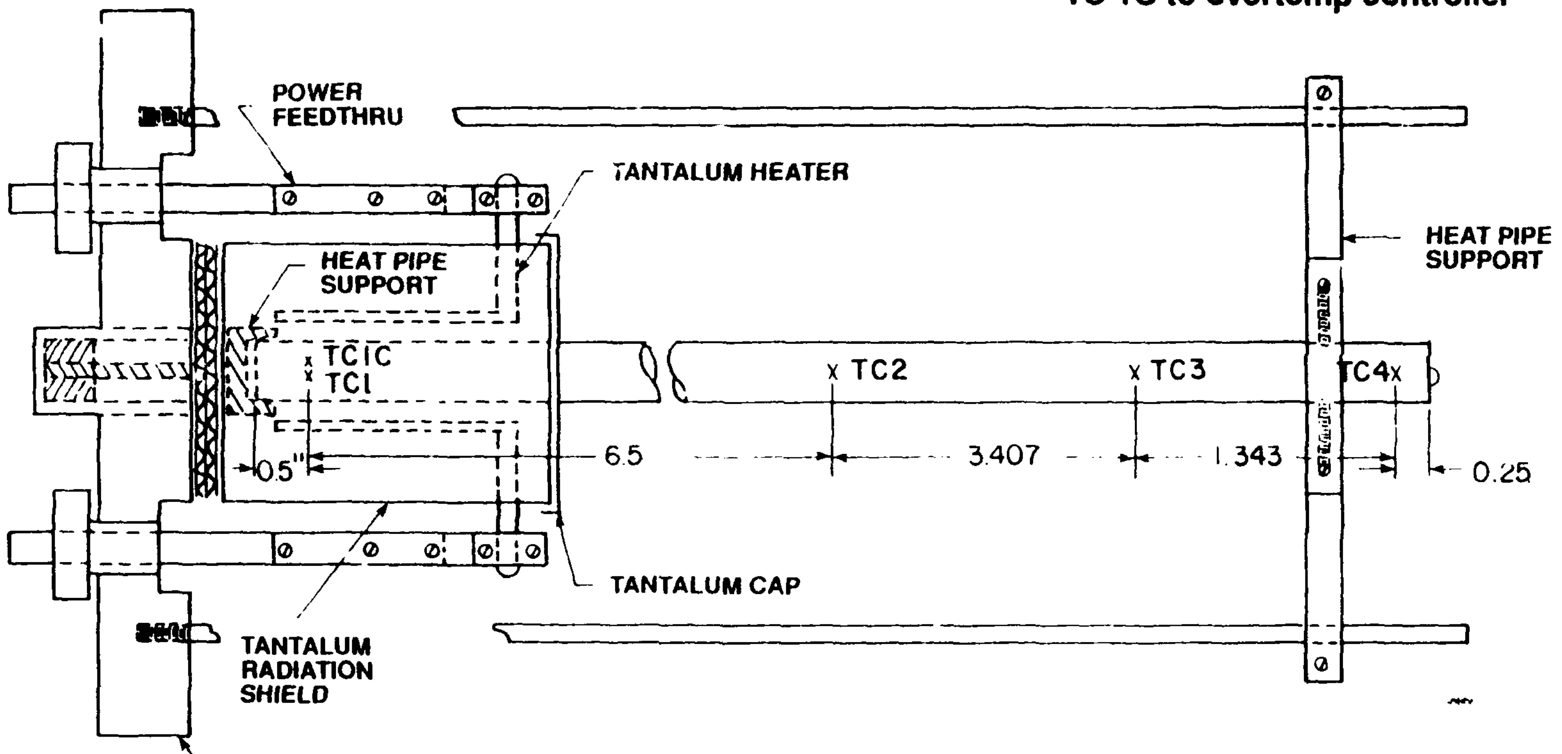


Figure 39. Titanium-Potassium Heat Pipe in Stand 3.

TEST STAND # 4

OAKRIDGE
STAINLESS STEEL
SODIUM FILLED
S/N 4
TC 1 thru 4 to Data Logger
TC 1C to overtemp controller

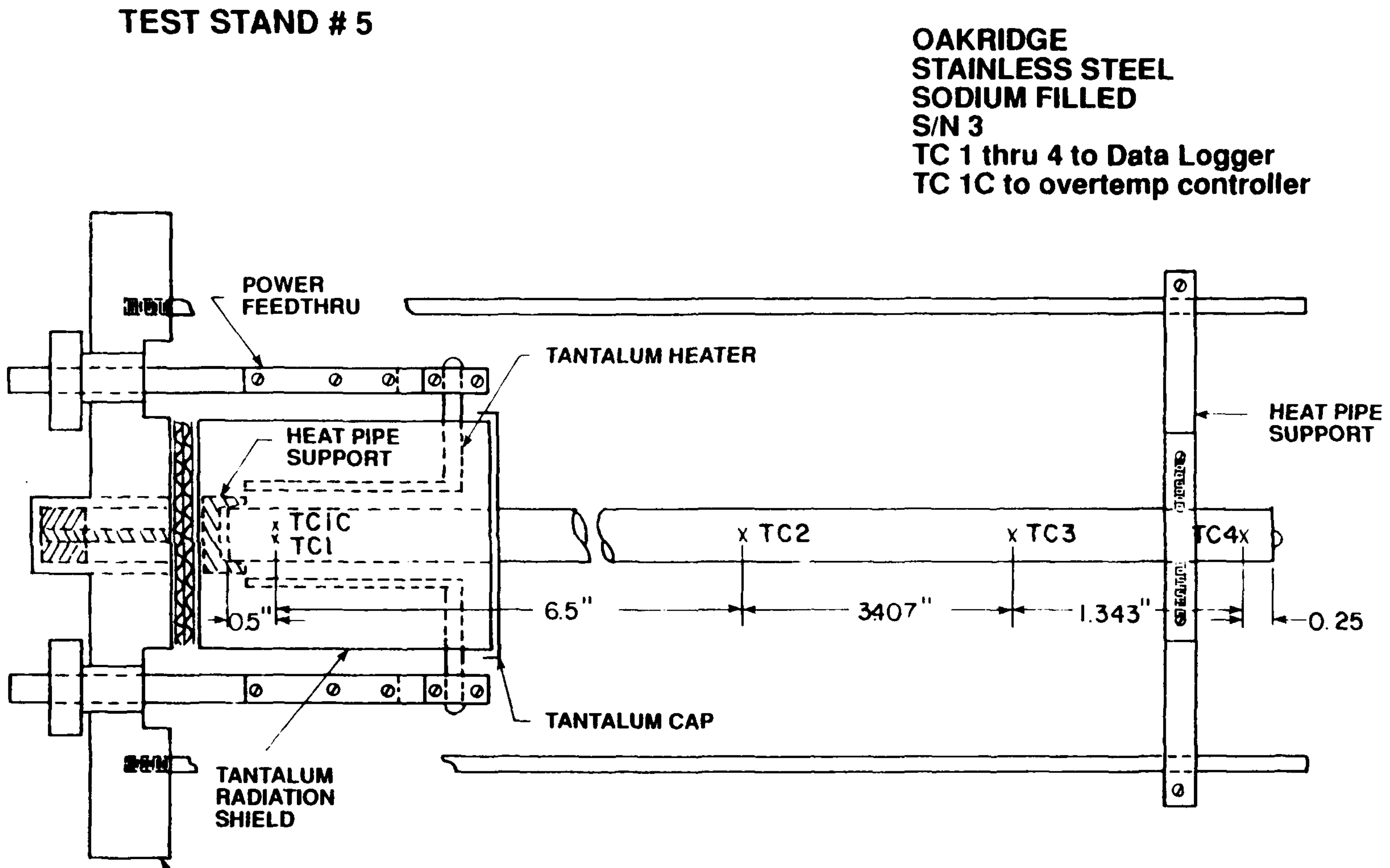


NOTE:

1). Heat pipe support modified for Oakridge 1" pipe.

2). Larger extra heat loss shields have been added to the existing small shields behind tantalum radiation shield.

Figure 40. SS304-Sodium Heat Pipe in Stand 4.



NOTE:

1). Heat pipe support modified for Oakridge 1" pipe.

2). Stainless steel shields added behind existing small shields behind tantalum radiation shield.

Figure 41. SS304-Sodium Heat Pipe in Stand 5.

TABLE 6. High Temperature Heat Pipe Life Test Data - Monthly Summary

Data Date: 9-20-90

HIGH TEMPERATURE HEAT PIPE TEST STANDS						
TEST STAND	HEAT PIPE MANUFACTURER AND SERIAL NUMBER	TEST START DATE	ELAPSED TIME HOURS	AVERAGE CONDITIONS		
				POWER INPUT WATTS	TEMP. °C	ΔT °C
1	Hughes S/N V67-013	05-01-86	37129	487	675.5	54.2
2	Hughes S/N 11	05-27-86	36356	107.0	342.8	247.4
3	Hughes S/N 10	10-02-87	23911	98.5	268.9	254.9
4	Oakridge S/N 4	07-16-86	34868	757.3	630.8	67.1
5	Oakridge S/N 3	08-07-86	34403	885.7	628.6	60.6

TEST CONDITIONS

1. ALL TESTS ARE UNDER VACUUM CONDITIONS (7.5 x 10^{-9} TORR OR BETTER) AND IN HORIZONTAL ORIENTATION.
2. HEATERS ARE TANTALUM RESISTANCE TYPE WITH RADIATIVELY COUPLED EVAPORATOR AND CONDENSER.
3. WATER COOLED TEST SHROUD.
4. STEADY STATE CONTINUOUS OPERATION.

HEAT PIPE DESIGN DETAILS CHART

TEST STAND	ENVELOPE	FLUID	OVERALL LENGTH INCHES	O.D. INCHES	EVAP. LENGTH INCHES	ADIABATIC LENGTH INCHES	COND. LENGTH INCHES	WICK MATERIAL
1	INCONEL 617	SODIUM	18	0.5	4.5	3.5	10	INCONEL 100 MESH
2	TITANIUM 99.6%	POTASSIUM 6.1 gm	15	0.75	5.5	3.5	5.9	INCONEL 100 MESH
3	TITANIUM 99.6%	POTASSIUM 6.1 gm	15	0.75	5.5	3.5	5.9	INCONEL 100 MESH
4	STAINLESS STEEL 304	SODIUM	12	1.0	4.5	0.0	7.5	STAINLESS STEEL 50 MESH
5	STAINLESS STEEL 304	SODIUM	12	1.0	4.5	0.0	7.5	STAINLESS STEEL 50 MESH

TABLE 7. High Temperature Heat Pipe Life Test Data - Annual Summary

Performance Parameter	Time * of Data at WRDC	Inconel 617-Sodium Test Stand 1	Titanium-Potassium Test Stand 2	Titanium-Potassium Test Stand 3	SS304-Sodium Test Stand 4	SS304-Sodium Test Stand 5
Power Input Q_{in} [W]	Year 1	500	185	155@	796	887
	Year 2	491	114	164	771	882
	Year 3	481	100	62	759	870
	Year 4	485	90	60	755	876
Adiabatic Operating Temperature T_{ADIA} [°C]	Year 1	695.6	511.3	426.7@	648.5	636.1
	Year 2	681.1	353.4	429.1	625.0	624.4
	Year 3	674.0	319.0	263.5	616.3	623.1
	Year 4	674.7	290.4	264.7	614.8	627.3
Evaporator to Condenser Temperature Difference ΔT_{EC} [°C]	Year 1	51.1	198.8	214.7@	87.3	76.8
	Year 2	54.9	245.3	202.0	68.9	62.4
	Year 3	56.3	255.4	255.9	67.1	57.8
	Year 4	54.5	264.0	257.9	71.2	58.2

* Data reference data: Year 1 = 7/18/87 Year 3 = 7/14/89
Year 2 = 7/15/88 Year 4 = 7/16/90

@ Data of 10/8/87

Evaluation Criteria: As in the low temperature heat pipes, three failure situations can be defined here: 1) hot spot development in the evaporator, 2) gas slug in the condenser and 3) burn-out or leak. The first two are slow and gradual symptoms whereas the last one is drastic. The success of a pipe lies in the accumulation of maximum test hours without failure. The test must be terminated if the pipe leaked or burnt out. A post-test cut-away examination must follow each failure for thorough analysis of the failure.

3.5 RESULTS AND DISCUSSIONS

In about 4-years, the high temperature heat pipes have accumulated 24,000-37,000 hours of life testing. The sodium pipes run more isothermally than the potassium pipes. (See Tables 6 and 7 for ΔT data.) The typical temperature profiles of these five heat pipes are plotted for three stages, namely the beginning, middle and the latest of the accumulated life test data. Figures 42-46 show these profiles.

Titanium-Potassium Pipes: There is a restriction on the maximum temperature at which a titanium heat pipe can be operated due to the poor high temperature strength of the metal. The ultimate tensile stress of titanium falls below 137.9 x 10^6 N/m^2 (20 kpsi) beyond 863K. Even though the potassium working fluid has an operating range of 500-1100K, the present titanium-potassium pipe has to be restricted to 863K. At this temperature, the pipe is not efficient and hence its poor performance. Both titanium pipes show deterioration of performance; the power input has dropped and ΔT has increased. This may be symptoms of noncondensible gas generation or wick damage at the evaporator. If this situation gets any worse, their performances may have to be monitored closely before shutting the tests down. On the other hand, if it continues as it is, then it may not be a concern. The primary purpose of the life test is to evaluate the titanium-potassium compatibility and not the transport performance.

Sodium Heat Pipes: All three sodium heat pipes are in excellent condition. They are isothermal within 100°C and operate near the optimum operating temperature for sodium (1000K). It is more likely that the sodium pipes could outlive the potassium pipes.

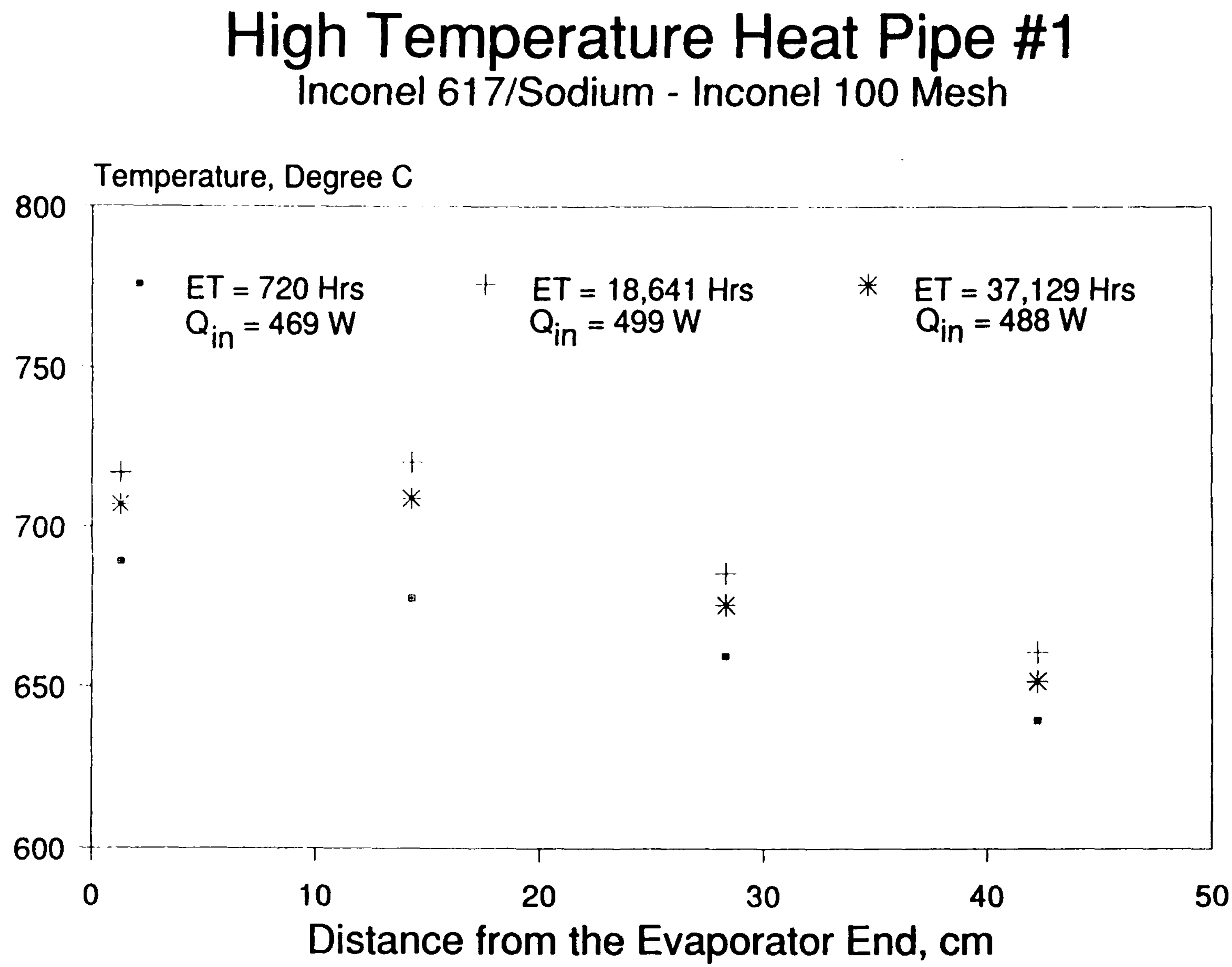


Figure 42. Axial Temperature Profiles of High Temp Heat Pipe Stand #1

Figure 42. <u>Temperature Profiles of Heat Pipe in Stand 1</u>.

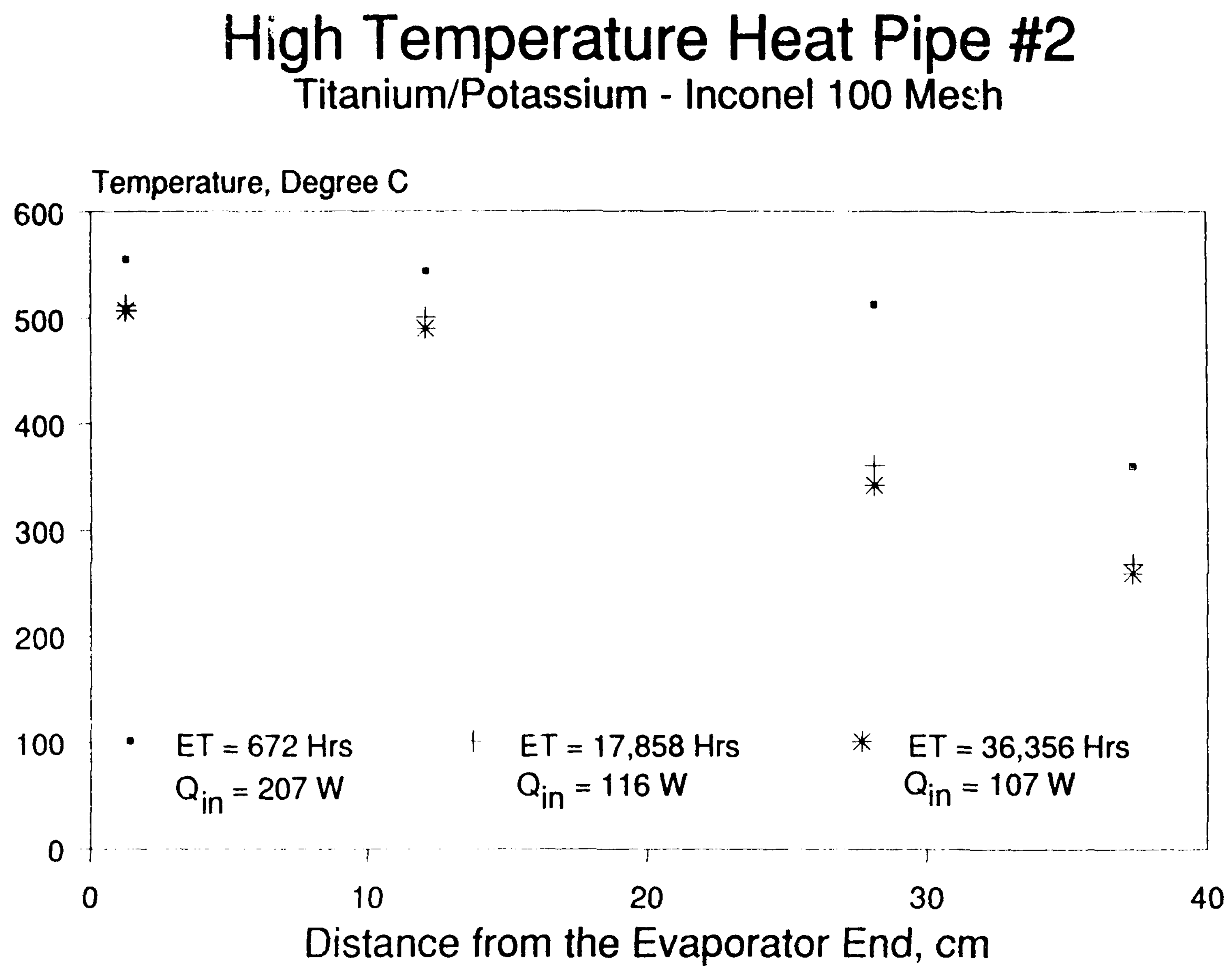


Figure 43. Axial Temperature Profiles of High Temp Heat Pipe Stand #2

Figure 43. Temperature Profiles of Heat Pipe in Stand 2.

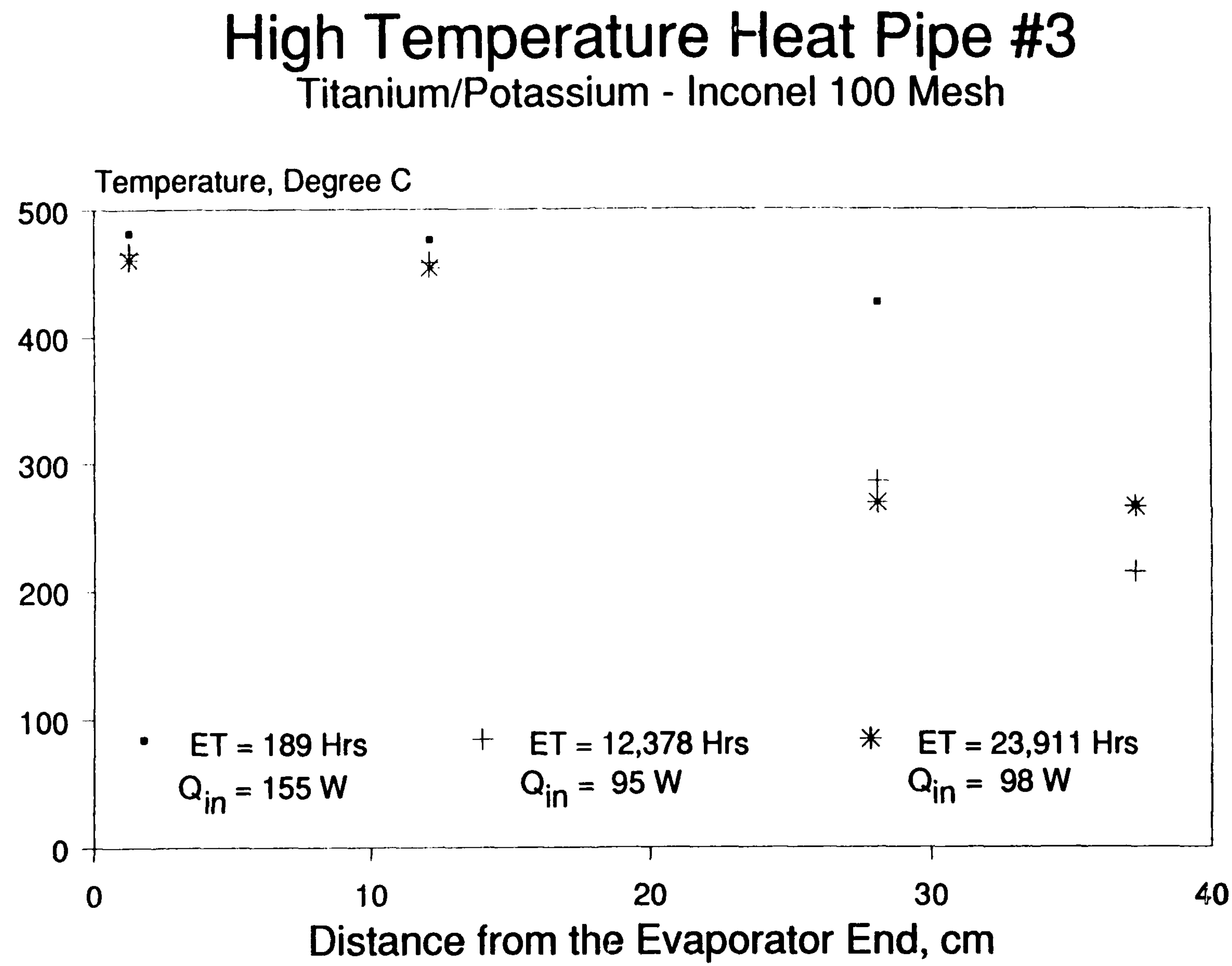


Figure 44. Axial Temperature Profiles of High Temp Heat Pipe Stand #3

Figure 44. __Temperature Profiles of Heat Pipe in Stand 3__.

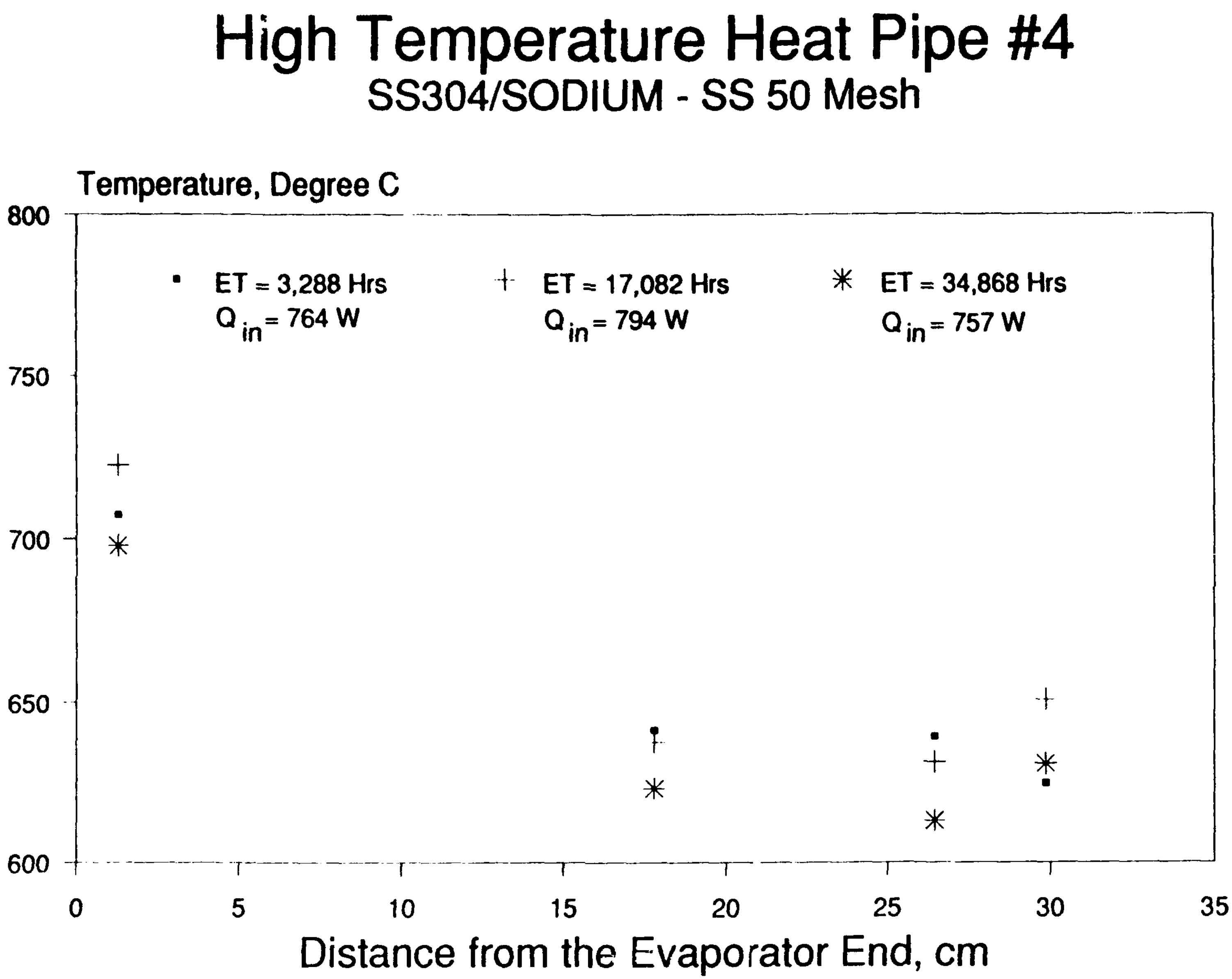


Figure 45. Axial Temperature Profiles of High Temp Heat Pipe Stand #4

Figure 45. Temperature Profiles of Heat Pipe in Stand 4.

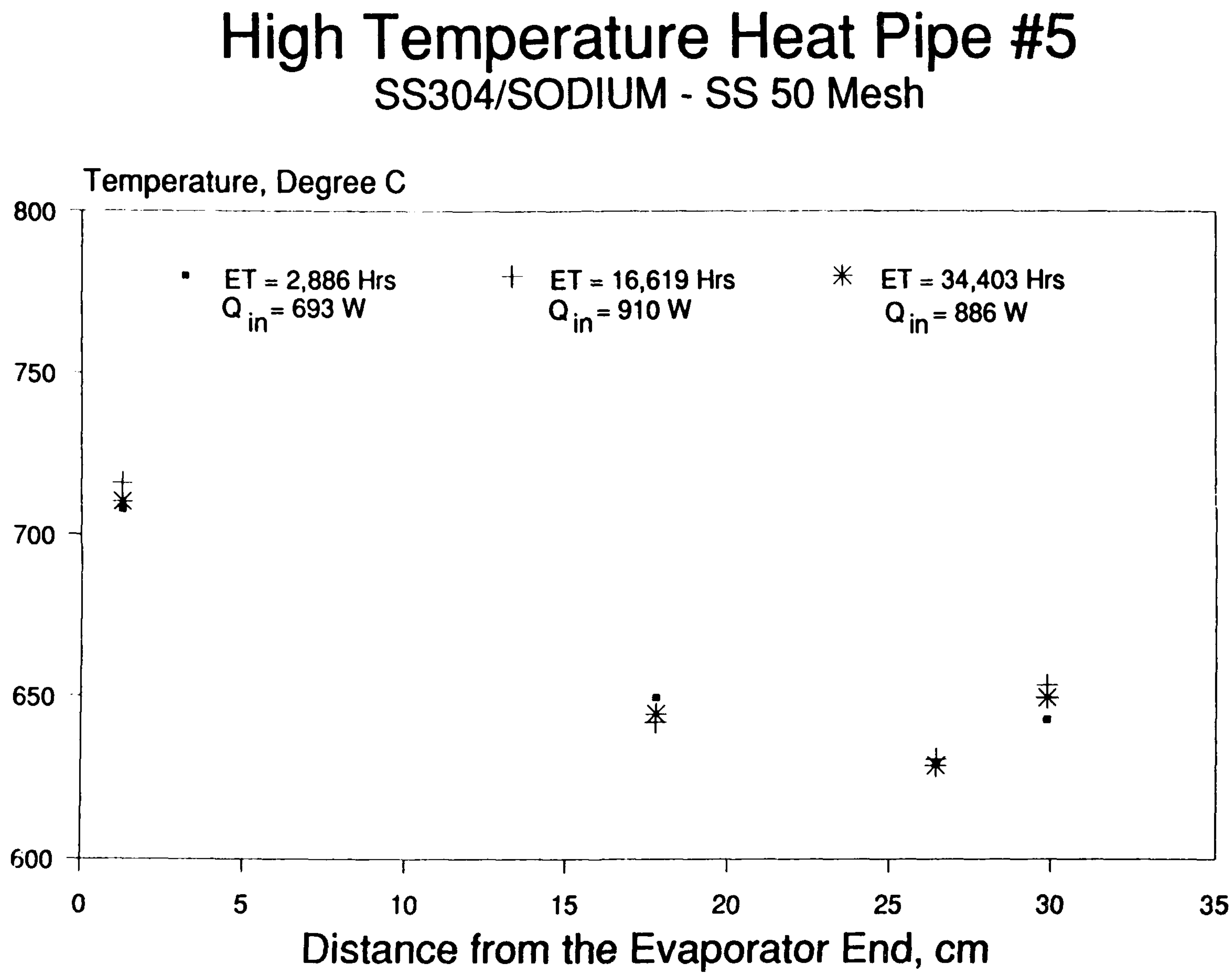


Figure 46. Axial Temperature Profiles of High Temp Heat Pipe Stand #5

Figure 46. <u>Temperature Profiles of Heat Pipe in Stand 5</u>.

3.6 RECOMMENDATIONS

1) The original design information about the process details, design capacity and wick details are not available for these pipes. These should be obtained from the manufacturers of the pipes and put on record with the test log books.

2) The monthly data logging must continue for future use and investigation.

3) The potassium pipes may be run more isothermally by reducing the condenser length. An extension of the adiabatic shield will be required to accomplish this modification.

4) The aging analog set point temperature controller may be replaced with new digital type instruments as in the low temperature test stands.

SECTION IV
CONCLUDING REMARKS

The heat pipe life test program represents a vital importance to the heat pipe research, manufacturing, and user organizations in terms of its technological usefulness. A great deal of time and resources have gone into this effort. This program, in its shape today, carries the continuity from the originating organization, NASA LeRC. Experimental investigations of this kind, primarily time effect studies, have significant wealth of information for the future scientific community.

The spacecraft-type low temperature ammonia and methanol heat pipes have surpassed 8-years of performance. On an average, the processing methods used in making these pipes seem to be adequate. Final post-test analysis will throw more light on this issue. With the advent of the computerized data logging, the time spent in maintaining these tests has become very minimal.

The sodium and potassium pipes have completed nearly 4-years of life tests. In a similar effort, water and mercury heat pipes have to be put on life tests. These pipes have very important application in radiator and energy conservation areas.

REFERENCES

1. Logbooks kept with each of the low temperature heat pipe test stands 1 through 30 at the Thermal Laboratory WRDC, Bldg. 18 G, Room 41-44.

2. W. B. Kaufman and L. K. Tower, "Evaluation of Commercially Available Spacecraft-Type Heat Pipes," J. Spacecraft Vol. 16, No. 2 March-April 1979. pp 98-103.

3. L. K. Tower and W. B. Kaufman, Procedures for Testing and Evaluating Spacecraft-Type Heat Pipes. Interim report for period August 1983 - December 1983 AFWAL-TR-84-2029. Aero Propulsion Laboratory, WPAFB, April 1984.

4. W. B. Kaufman and L. K. Tower, Compatibility of Sodium and Lithium in Superalloy Heat Pipes, Final Report for period 1 January - 31 December 1984. AFWAL-TR-85-2006. April 1985.

5. L. K. Tower and W. B. Kaufman, "High Temperature Heat Pipe Research at NASA Lewis Research Center," Paper No. 78-438. A collection of Technical Papers 3rd Intl. Heat Pipe Conference, Palo Alto, California. May 1978.

6. A. S. Reyes, J. R. Brown, W. S. Chang, and R. Ponnappan "Gas Generation Test Data and Life Tests of Low Temperature Heat Pipes," AIAA 90-1756, 5th Joint Thermophysics and Heat Transfer Conference 18-20, June 1990. Seattle, Washington.

7. Logbooks kept with each of the high temperature heat pipe test stands 1 through 5 at the Thermal Laboratory, WRDC Bldg. 18G, Room 41-44.

U.S. Government Printing Office 548-076